Results from the WirelessCabin Demonstration Flight

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***Abstract*— The EC project WirelessCabin aims at providing aircraft passengers and crew members with heterogeneous wireless access solutions for in-flight entertainment, Internet access and mobile/personal communications. It is expected that aircraft passengers will be offered the same wireless services for personal and multimedia communications as they are on ground, consisting of different overlaying cellular access networks, e.g., UMTS, IEEE 802.11x W-LAN and Bluetooth. A communication architecture was developed and demonstrated in flight. This paper reports on the results from the demonstration flight that was carried out in an Airbus A340-600 in September 2004.**

***Index Terms*—Aeronautical communications, GSM, heterogeneous networks, satellite communications, wireless access**

I. Introduction

AERONAUTICAL communications for aircraft passengers become increasingly interesting for airlines, service operators and passengers [1]. The IST WirelessCabin project aimed to pave the way by developing a network architecture for different radio access technologies, by investigating radio propagation inside the aircraft cabin and interference to aircraft avionics and ground networks, and by developing a in-flight demonstrator. A variety of WirelessCabin information can be accessed on the website www.wirelesscabin.com. This paper describes a test flight in an Airbus A340-600 that has demonstrated all cabin services.

II. WirelessCabin Architecture Overview

The Wireless Cabin system [1] can be considered as made up of 6 different domains: (i) Local Access Domain, (ii) Service Integration Domain, (iii) Transport Domain, (iv) Service Provider Domain, (v) Public Network Domain, and (vi) Home Network Domain. The Local Access Domain includes the several wireless access technologies such as 2G/3G mobile networks, WLAN and Bluetooth.

The Service Integration Domain handles all the heterogeneous traffic to/from the Local Access Domain and to/from the satellite. From a service prospective it schedules the session requests and the related QoS, monitoring resources so as to guarantee the QoS. Together with the Service Provider Domain, it handles the sessions through a common set of protocols, independently of the local wireless access the session is initiated from. The Transport Domain is basically the satellite segment and it provides connectivity between the Service Integration Domain and the Service Provider Domain so as to handle both voice and data sessions in a seamless way. The Service Provider Domain is the core of the system together with the Service Integration Domain. It acts as a master in the one-to-one communication with the Service Integration Domain and as such it can handle a number of clients (i.e. aircrafts) at the same time. It is able to perform authentication for all the clients and their related users attached to it acting as a centralized authentication point for all the aircrafts connected to it. Moreover it is able to collect accounting information and send it to the related Home Network when necessary. From a system monitoring perspective, the Service Provider Domain is able to monitor the Service Integration Domains connected to it and to send operation commands when necessary for OMS purposes. The Service Provider Domain interfaces with the Home Network Domain and as such is able to convert the signaling so as to forward it through the same set of protocols across the satellite. Figure 1 shows the Wireless Cabin system architecture.

As for the Local Access Domain it is worth mentioning the UMTS local access. Figure 1 shows all the UMTS network elements that must be put on board the aircraft. This configuration that at first glance could seem the most complicated, actually reveals to be the best approach for convergence purposes and also for average signaling load over the satellite link. Both CS and PS domains are here shown but for a pure IP Multimedia architecture the CS domain does not need to be deployed, which means that the MSC is not necessary anymore as both voice and data are handled by the PS domain (and therefore by the SGSN and GGSN). The SGSN and MSC on board the aircraft are a light version of the standard entities; for instance they do not implement full VLR

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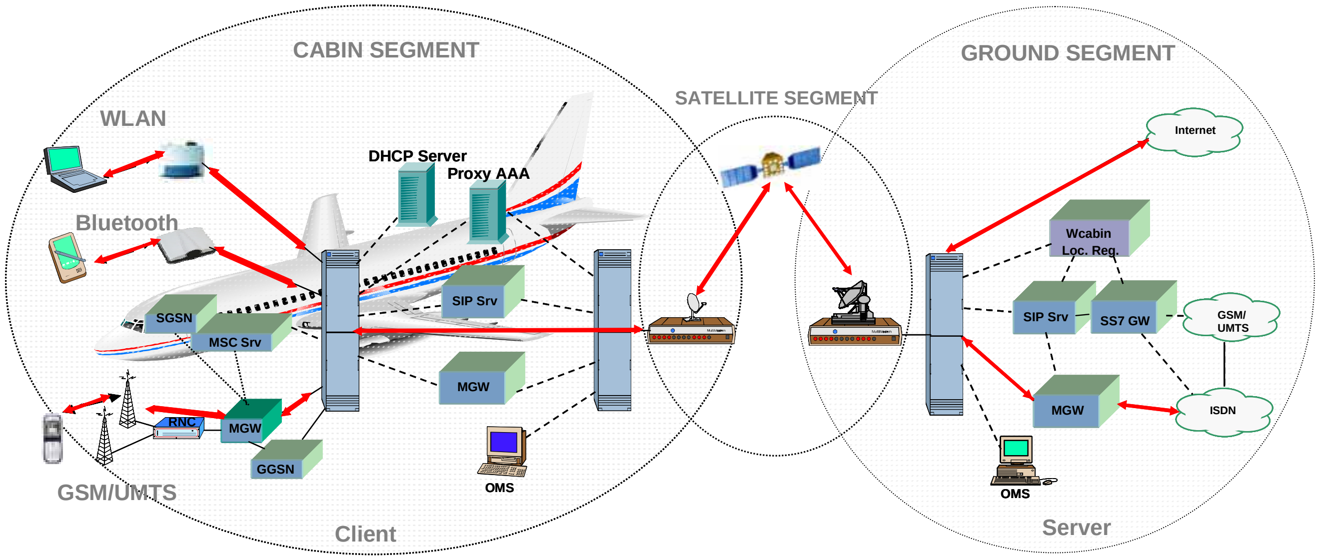

Fig. 1. The WirelessCabin System Architecture

functionality, as the full profiles of the users are stored in the Service Provider Domain. Moreover these entities implement both SIP and RADIUS protocol, acting as server for SIP and client for RADIUS, which guarantees convergence and therefore having always the same set of protocols between the Service Integration Domain and the Service Provider Domain. The SIP server/MGW allow handling the PSTN satellite connection (when available) so that the session establishment can take place in the same fashion independently of the satellite service offered. This means that also in this case the session establishment takes place through the same set of protocols. Moreover the MGW can implement a transcoding when necessary. In fact it can happen that the negotiated end-to-end codec for voice.

The Service Provider Domain has got a user's database, called WCabin location register where user's profiles are stored; from a UMTS point of view, it corresponds to the VLR and it also acts as a centralized unit for temporary number assignment for incoming calls. The WCabin location register has got AAA functionalities and together with the proxy AAA server in the Service Integration Domain, authenticates the users wanting to access the system. A SIP server/MGW allows interconnection with the PSTN network, while an SS7 gateways will be used to convert SS7 signaling from 2G/3G home networks into Radius/SIP messages. This will allow having a standard attachment mechanism, regardless of the local access envisaged.

III. Demonstrator Setup

The basic functionalities of the system architecture were implemented in an demonstrator. The main component in the aircraft was a Aircraft Service Integrator (ASI). Basically, this is a Linux box using SuSE 8.2 as operating system and kernel 2.4.20. It is equipped with a 2.4 GHz processor, 6 Ethernet cards (Linked to interfaces eth0, 1, 2, 3, 4 and 5) and one ISDN card (Interface ippp0). It runs a certain number of applications separated in two parts: the Local Access Domain (LAD) and the Service Integration Domain (SID). There were two types of satellite connections used, both using the Inmarsat network. The first one is using a Swift 64 ISDN channel on the main 4 Inmarsat satellites. One Swift 64 channel is offering a dedicated link with 64 kbps (Kilo bits per second) of data rate. On board the Airbus A340-600 used for the test, a phased array antenna is installed at the top of the cabin and a SatCom terminal is mounted in the electronic bay of the plane. Antenna and SatCom terminal are built by Rockwell-Collins. The satellite used g the flight test is AOR-E and the ground station is located in Burum (Netherlands). After that, the call is routed via the terrestrial ISDN network to the GSI located in Oberpfaffenhofen (Germany).

IV. Test Flight

Several demonstration events have been conducted:

- a ground laboratory during the WAEA (World Airline Entertainment Association) workshop on Wireless Onboard in Hamburg, Nov 11-13, 2003
- ground life demonstration during the International Air Show ILA, May 2004 in Berlin
- **September 13, 2004: Test Flight at Airbus (Toulouse)**

As highlight of the demonstrator development and integration, a test flight was carried out with the complete WirelessCabin demonstrator set-up. The test flight lasted about 2,5 hours and was conducted from Toulouse some way above the Mediterranean Sea towards Corsica and then back to Toulouse.

The measurement flights were evaluated in the laboratory. It was aimed to evaluate the performance of the WirelessCabin demonstrator architecture. Both the voice samples and IP

Fig. 2. Airbus A340-600 test flight team and test installation rack

packets were collected during a series of ground-test, flight-test and lab-test carried out. The main objective is to evaluate the voice quality over the WirelessCabin system and its system performance. The evaluation of the former makes use of speech recognition techniques [2] and power spectral density functions in order to investigate the voice quality in terms of signal-to-noise ratio. The system performance is evaluated in terms of throughput, end-to-end delay, connection establishment time and authentication delay.

During the test flight passengers could make and receive calls with GSM handsets or VoIP equipment. Typical IP services such as web browsing, email, VPN to company intranet and streaming application have been shown. Onboard servers held airline specific content such as destination information. The cabin crew used personal digital assistants (PDAs) for crew communication but also for airline specific services such as in-flight shopping and credit card billing. Also a simulation of an emergency situation was performed with wireless telemedicine equipment. During such emergency the system automatically gave priority to the telemedicine equipment and the crew communication, while passenger services were shut down.

The advanced network technology as developed in the project were demonstrated as well, such as control the services, e.g., incoming calls could be blocked during defined flight phases in order to inhibit ringing of mobiles for noise comfort in the cabin, while data services such as GPRS or IP are allowed. Furthermore, the system supports quality of service across the different air interfaces of GSM or WLAN. An advanced billing system was addressing airline specifics such as support of mileage and partnership programs.

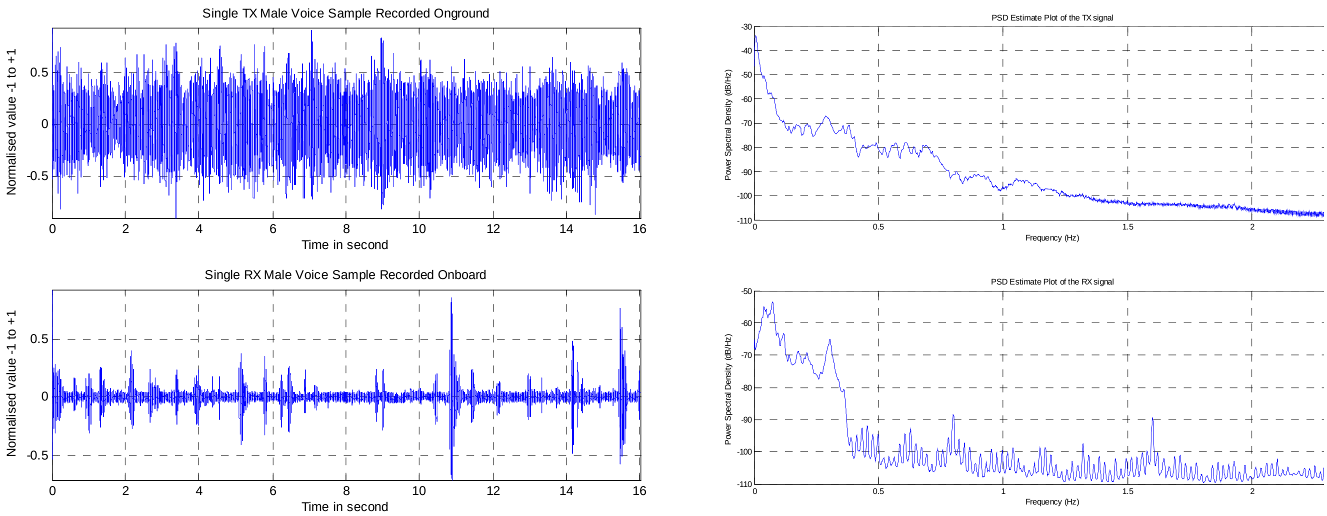

Fig. 3. Amplitude-time and the PSD plots of the male voice sample with +10dB noise

V. Test Flight Results

The following sets of data have been collected during those trials in order to evaluate the performance of the system:

- Voice samples
- IP packets via Ethereal
- Power control measurements

The voice samples are used to evaluate the end-to-end delay as well as to perform amplitude-time and spectral analysis in order to examine the voice quality over the transmission path. IP packets have been captured using Ethereal and they are used to evaluate the connection establishment time and the delay between the SID and the SPD of the WirelessCabin system architecture. Analysis has been carried out for the following scenarios using the voice samples and the captured IP packets:

- Onboard GSM to onground terrestrial GSM
- Onboard GSM to onground terrestrial telephone
- GSM to onground VoIP client
- Onboard VoIP to Onground VoIP client
- Real-time radio streaming via Internet
- Authentication analysis

The performance of the power control technique has been evaluated through the power control measured data set. The following sections provide exemplary results.

Background noise of the aircraft cabin can deteriorate the GSM speech quality. Analysis was conducted on the effect of the background noise. During the trials, different noise sample levels were used to evaluate the system performance. For instance assuming that a sound level of a normal conversation in flight cabin is around 70dB, noise sample levels of +6dB & +10dB were added.

Figure 3 shows the amplitude-time plots of the male voice TX and RX signals where the background noise level of the input signal has been reduced significantly results in a much more desirable speech-like at the RX terminal. Along the signal path of the system, it is believed that the only two possible ways for noise rejection would be the input/output GSM codec and the limited frequency response of the system. The latter applies only if the background noise consists of high frequency components. Both low frequency components as well as high frequency components are in the cabin background noise sample. Furthermore a 15dB drop is shown in the signal at around 1000Hz which coincides with the wave property of a male voice sample.

Table 1 summarises the results obtained from the voice call data analysis.

- For each scenario, the average satellite downlink delay is smaller than average satellite uplink delay
- When considering traffic in one direction, the four scenarios get very similar average delays. The only difference is that the average delay for traffic originating from VoIP clients is a little smaller than the average delays originating from GSM and terrestrial fixed telephone line.
- In the scenario for calls originating from VoIP client to another VoIP client, there are higher percentages of satellite delay, because the SID processing time is quite small compared to other scenarios. This is also the reason why the average delays of the VoIP to VoIP calls is smaller than the average delays of other scenarios on same direction. (See Annex C for explanation on how the different delays are determined).
- Standard deviation for GSM to GSM calls, GSM to VoIP calls and GSM to fixed terrestrial telephone calls are rather similar. This means that the changes/ranges in the delay for these scenarios are quite similar. However, the standard deviation for VoIP to VoIP call is smaller compared to other scenario. This indicates that the delay change for this scenario is smaller and the traffic is more stable compared with the other three scenarios
- The throughput value indicates that data transmission speeds are similar for all voice calls, irrelevant of the method used in establishing the voice calls. This is also true for traffic originating from different directions

For all voice calls, similar throughputs and average packet delays are detected. The packet delay change range is very small and there are almost are no packets lost. All these factors prove that in the WirelessCabin system, the voice traffic is rather stable, which can guarantee good quality voice calls.

TABLE 1: Comparison of voice call results

	GSM call GSM		**GSM call VoIP**		**GSM call telephone**		**VoIP call VoIP**	
	From onboard	From onground	From onboard	From onground	From onboard	From onground	From onboard	From onground
Satellite delay	0.404584s	0.464173s	0.417478s	0.447931s	0.365052s	0.504986s	0.396852s	0.467186s
Average delay	0.44238s	0.5038s	0.448519s	0.478685s	0.401081s	0.542393s	0.398902s	0.46931s
% of Satellite delay	91.46%	92.13%	93.07%	93.57%	91.01%	93.1%	99.49%	99.55%
Standard deviation	0.077256	0.07545	0.062545	0.062794	0.065678	0.066315	0.009338	0.018444
Throughput (kb/sec)	18.356	18.178	18.349	18.57	18.345	18.323	18.309	18.502
Packet lost	0	45	1	0	4	0	0	0

Table 2 shows a diversity of system performance across different scenarios for the End-to-End delay results. Depending on the actual signal flow, inter-scenario similarities can be drawn. For instance, the GSM-to-GSM communication shares roughly the same physical path as GSM-to-Terrestrial-Telephone therefore the End-to-End delay measurements are proven to be fairly close. The only cause for additional delay in GSM-to-GSM would be the extra routing time between the SPD to the GSM backbone and eventually reaching the local BTS. Similarly, for the scenarios which have GSM phone as one end of the user device has shown a promising background rejection noise property which is advantageous for use within the typical the WirelessCabin environment where in-flight background noise dominates and can possibly determine the voice quality of the system if noise-rejection is not available on the users' devices. Amongst the four different scenarios, the signal-to-noise ratio drop between the transmitting and the receiving signals is roughly 5dB except in the GSM-to-Terrestrial case where the signals are corrupted by the GSM-interference.

During the Flight an onboard Billing System was also demonstrated. The prototype, collected accounting information from the on board Radius server, and calculated rating based on passenger billing categories. Additional CDR were simulated, as well as crew or passenger initiated service such as duty free purchases, In Flight entertainment, and on Board restaurant orderings. A single bill was produced for all passengers of the test flight and the bill was also sent via E-Mail to the passenger mailbox. Furthermore, using a dedicated Bluetooth connection between the Billing system and the Sony Ericsson P900 phone, two applications were shown: Electronic Bill presentation for passengers and remotization of duty free purchase for crew members. This Bluetooth connection worked for distance up to 30 meters between the mobile phone and the Billing system.

CONCLUSIONS

The results obtained from the test scenarios which have GSM phone as one end of the user device has shown a promising background noise rejection property which is advantageous for use within a typical WirelessCabin environment, where in-flight back-ground noise dominates and can possibly determine the voice quality of the system if noise-rejection is not available on the users' devices.

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Fig. 4. PDA with Inflight Shopping and billing application

VI. REFRENCES

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TABLE 2: Voice Performance Analysis Summary

	GSM-to-GSM	**GSM-to-Tele**	**GSM-to-VoIP**	**VoIP-to-VoIP**	**Radio**
Average delay					
Air to Ground :	1.1444 sec	1.0078 sec	0.843 sec	0.6716 sec	-
Ground to Air :	1.0978 sec	0.944 sec	0.598 sec	0.9734 sec	-
SNR drop	5.57dB	10.1106dB	5.161dB	4.3787dB	-
Cut-off freq.	4000Hz	4000Hz	4000Hz	4000Hz	Laptop:4000Hz PDA:12000Hz
Noise-Rejection	Good	GSM side	GSM side	No	-