

ETSI White Paper No. 4 GSM operation onboard aircraft

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In September 2000 he joined ETSI's Mobile Competence Centre, in which he took a leading role in the support of various 3GPP and ETSI committees, mostly focusing on radio interface standardization. These included the 3GPP Radio Access Networks (RAN) Technical Specification Group and its Working Group 4 (Radio Performance and Protocol Aspects), ETSI's Mobile Standards Group and its working groups, and ETSI's Railway Telecommunications Technical Committee.

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GSM operation onboard aircraft

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This White Paper outlines the work of ETSI (the European Telecommunications Standards Institute) in specifying a system for providing GSM™ communications onboard civil aircraft. The technology is an adaptation of the conventional terrestrial GSM, which has also been specified by ETSI. In addition, this document summarizes the current European regulatory situation with regard to such systems.

The White Paper also identifies several issues which will have to be taken into consideration when deploying “GSM onboard”, but which extend beyond technology and regulation: they are thus outside the scope of ETSI.

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Foreword

For several years the aircraft industry has looked for a technology to provide at a reasonable cost a phone service onboard aircraft. Since 1996 some studies have taken place in ETSI to support the GSM (or other similar technologies) services to cover this requirement. One of the main problems to be solved was linked with the non-confinement of Mobile terminals inside the plane. An aeroplane is not a Faraday Cage: as such it cannot prevent the reception of the terrestrial networks and hence could damage the use of the terrestrial networks by creating interference on the Random Access Channel. This document provides an overview of the problems and presents the solution found which will allow onboard phone service at limited cost for the end users.

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GSM operation onboard aircraft

Introduction

Telephony Services onboard planes are not something new. The Terrestrial Flight Telecommunication System (TFTS) [1] allowed air travellers of the nineties to place calls using handsets attached to the seats and paying with their credit cards. TFTS provides a radio link between aircraft and ground stations which have access to public fixed telecommunications networks. The radio system is similar to the cellular systems of the land mobile service, although cells are wider (240 km) and reach higher levels (10 000 m). Commercial demand for TFTS failed to sustain initial expectations, probably due to the perceived high cost of the service and the lack of the personalized features that users now enjoy in their personal mobile phones, and the service has now ceased.

More recently, Boeing has been offering its “Connexion” service through selected airlines [2]. Connexion provided Internet access to travellers, who also charge their credit cards for the service. The system used a satellite link to connect to the ground and a wireless local area network (WLAN) onboard for the access the system. Again, due to the lack of market demand [3], Boeing announced that the service would be discontinued at the end of 2006.

Many organizations have been looking at the possibility of supporting a GSM service on aircraft – for instance, the ETSI SMG committee studied this as long ago as 1988. Recently there has been more activity in this area. Several companies are looking into offering onboard GSM service as a feasible commercial venture, and some airlines have issued press releases announcing trials and dates for the service. Aircraft remain one of the few places where mobile phones cannot yet be used. Once that this restriction is removed, it can be expected that the service becomes as popular as it is on the ground. The user experience will be personalized and much like international roaming: same terminal, same agenda and, presumably, a pricing scheme similar to that for international calling. On the basis of these key differences, it is the belief of the proponents of GSM onboard (GSMOB) that this system will succeed where TFTS and Connexion failed.

This paper briefly addresses the technological and regulatory issues regarding GSM onboard; describes the system architecture; explains some of the technical challenges, in particular the impact of the system on terrestrial mobile networks and, finally, summarizes ETSI’s involvement and the development of the necessary standards.

Regulatory background

Two recent developments in relevant European regulatory groups have increased the likelihood that the GSM onboard service can be successfully launched: the decision of TCAM (European Commission Telecommunication Conformity Assessment and Market surveillance committee) that the complete system falls under the R&TTE (Radio & Telecommunications Terminal Equipment) Directive [4], and the development of the spectrum regulatory framework in the Regulatory Affairs Working Group (WGRA) of the Electronic Communications Committee (ECC) of CEPT¹. There has also been considerable consensus around a regulatory framework in the Asia Pacific region.

Regulatory developments within Europe commenced in CEPT WGRA in July 2004 when the draft framework was proposed. Consequently, the spectrum engineering group (CEPT / ECC / WGSE) was requested to investigate the compatibility of such a service with existing systems.

CEPT WGSE Project Team SE7 commenced the compatibility study in January 2005. The result of the work is an ECC Report [5], published in September 2006. This Report specifically addresses the impact of the GSMOB system on terrestrial GSM, UMTS (WCDMA (UTRA FDD)), FLASH-OFDM and CDMA2000 technologies.

On the basis of the regulatory developments mentioned above and the Report produced by SE7, CEPT WG RA produced and submitted for public consultation a draft ECC Decision on GSM onboard aircraft. The Decision [6], which was published in December 2006, will allow operation of a GSM onboard system, compliant with the requirements laid out in its Annex, according to the licensing conditions for the use of spectrum in the country of registration of the aircraft. It also requires that the equipment onboard complies with the R&TTE Directive.

¹ Conférence Européenne des Administrations des Postes et des Télécommunications

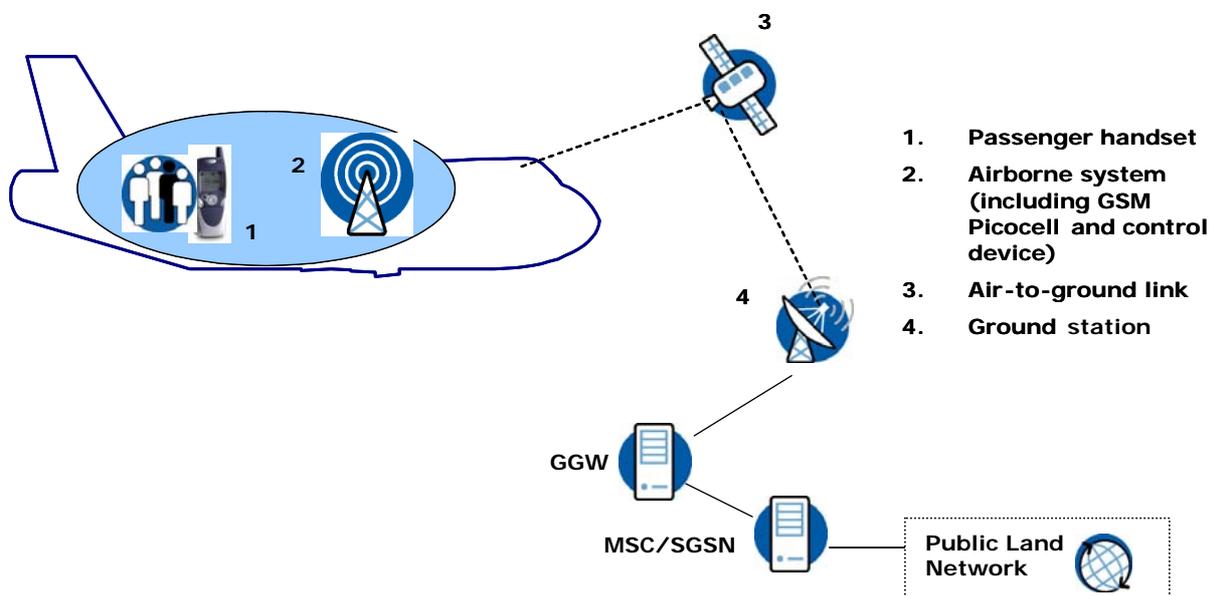
Service description

GSMOB mobile services will allow airline passengers to use their own mobile terminals during certain stages of flight. Passengers will be able to make and receive calls, send and receive SMS text messages and use GPRS functionality. The system provides mobile visited network access, meaning that the onboard network is run by a licensed operator with roaming agreements with the passengers' home operators and that the call will be billed to the user like any roaming call.

The frequencies used for onboard communications are in the GSM1800 band. The reasons for this choice are mainly technical: the minimum transmit power for a terminal in the 1800 MHz band is lower than in the 900 MHz band (0 dBm instead of 5 dBm), and emissions at higher frequencies present higher path loss. These characteristics make it easier to avoid interference to the ground systems as explained later. In addition, the vast majority of multi-band GSM units support the 1800 MHz band.

System description

The terminals will connect to an onboard pico Base Station using the standard GSM radio interface. The onboard cell is connected to the terrestrial networks through a satellite link. The figure below shows the functional overview of the system:



Functional overview of the GSM onboard system

GSM onboard will be deployed in aircraft flying over terrestrial networks, very often over more than one country. The system must ensure that onboard terminals do not

attempt to communicate or interfere with terrestrial networks, and the system itself must not interfere or attempt to communicate with ground terminals. During the phases of the flight that the service is not active, such as during take-off and landing, passengers must switch off their mobile terminals.

The system is operational during the top of ascent, cruise and commencement of descent phases of the flight, only when the aircraft is more than 3000m above ground level.

There are several technical and operational methods to increase the electromagnetic isolation between the GSMOB and the terrestrial networks. One of these is the use of a "Network Control Unit" (NCU) as described below, but other methods, like radio frequency (RF) shielding, can be used in combination with the NCU.

The CEPT Decision lays out clearly the type of terminals that can be used. When active, the system is required to prevent terminals from registering to ground networks operating in the following bands:

- 450 – 470 MHz
- 876 – 915 MHz / 921 – 960 MHz
- 1710 – 1785 MHz / 1805 – 1880 MHz
- 1920 – 1980 MHz / 2110 – 2170 MHz

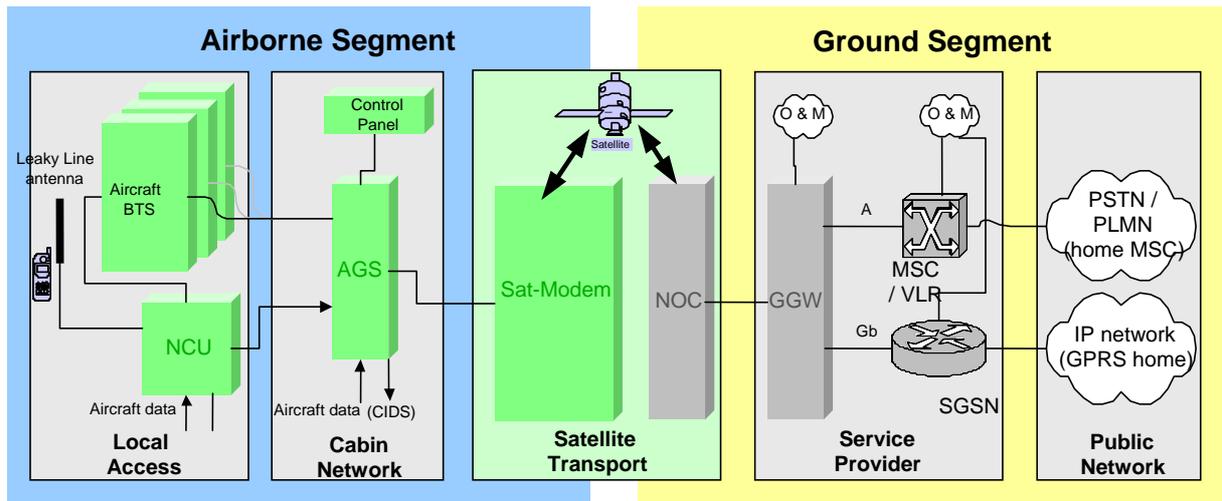
This requirement is addressed to cover the CDMA-450/FLASH-OFDM, GSM in the 900MHz and 1800MHz bands, and UMTS (WCDMA) in the 900 MHz, 1800MHz and 2GHz bands.

Terminals with support of other bands or technologies will not be prevented from connecting to ground networks, and may be capable of doing so if the corresponding band or technology is present in the ground. Under present regulatory conditions these other bands and technologies might still be banned, but in practice the requirement covers all terminals and networks used in Western Europe.

System architecture

There is no unique or standardized way of implementing the system. In particular, multiple or single leaky feeders can be used for transmitting signals within the cabin and the location of these feeders will depend on the specific solution and/or aircraft. This section follows the model used by CEPT in its compatibility study.

A typical GSM onboard system can be split in two parts, the airborne segment and the ground segment:



Architecture of the GSM onboard system

The airborne segment consists of the local access domain and the cabin network domain:

- The local access domain contains the Base Transceiver Station (BTS), providing GSM access, and the NCU. The purpose of the NCU in conjunction with the GSM pico-cell is to prevent terminals from accessing terrestrial networks, and to control the radio frequency emissions of these terminals in the bands protected by the system;
- The cabin network contains an Aircraft GSM Server (AGS) that integrates the main modules onboard, i.e. the BTS, the NCU and the Satellite Modem.

The ground segment consists of a service provider domain and the public network domain:

- The service provider domain hosts communication controller functions that act together with the AGS functions in the aircraft. For this purpose, a Ground Gateway (GGW) and GSM visited network components (VMSC² and SGSN³) are required. Their main features are to perform the routing towards the aircraft and to interconnect the aircraft traffic with terrestrial backbone networks of the Public Network Domain;
- The public network domain provides the interconnection of the call, data or signalling communication to the relevant public network end points.

² Visited Mobile Switching Centre

³ Serving GPRS Support Node

The key system components of the system are described in more detail below.

- **Cabin Antenna** The antenna is shared between the onboard BTS and the NCU. The typical implementation is a leaky feeder running along the cabin ceiling. Depending on the cabin and on the desired areas of coverage, multiple feeders or point source antennas could also be envisaged.
- **AGS – Aircraft GSM Server** The AGS forwards the data streams between the onboard BTS and the ground. The AGS manages the satellite link communication, controls the BTS, monitors the NCU output power level and manages the Operations and Maintenance functions. The crew will be able to access the system through the control panel.

The aircraft data contains aircraft information such as altitude, aircraft position and flight phase.

- **Satellite link** The onboard satellite components consist of the satellite modem and the external aircraft satellite antenna. The satellite antenna receives and transmits the signals from/to the satellite system. The link will be provided by a satellite operator such as Inmarsat.
- **Network Control Unit (NCU)** The purpose of the NCU is to stop terminals onboard from connecting to ground networks. To ensure this, it raises the RF noise floor inside the cabin to a level that effectively covers the signals from the ground base stations. The signal generated by the NCU is a band-limited white noise and, in the European configuration, it will blanket the following bands:
 - GSM- and WCDMA/UMTS-900 downlink (921 – 960 MHz)
 - GSM- and WCDMA/UMTS-1800 downlink (1805 – 1880 MHz)
 - UMTS UTRA-FDD 2GHz downlink (2110 – 2170 MHz)
 - CDMA-450/FLASH-OFDM downlink (460 – 470 MHz)

The unit will not transmit below 3000m. The power level of its emissions will depend on the frequency band and on the altitude (increased altitude means decreased signal strength received in the aircraft from terrestrial networks).

- **Onboard BTS** GSM connectivity is provided by a standard GSM pico-BTS. The BTS will support GSM and GPRS services in the DCS1800 band (1710-1785 MHz and 1805-1880 MHz).
- **Mobile station** The passengers' terminals will be standard GSM and must support the GSM1800 band. The BTS will command the terminals to only transmit at their minimum possible level, after initial registration.

Radio engineering aspects

The challenges in the design of the GSM onboard system arise from the particular RF scenario it is intended for. There are a number of issues that set the system apart from ground mobile networks; these have been carefully considered by operators, manufacturers and regulatory bodies when engineering the system and setting up the regulatory framework:

- **Disturbance to ground networks.** Depending on the power levels and the effective shielding of the aircraft, the transmissions from equipment onboard may interfere with ground networks. Due to the altitude and line of sight propagation, the interference may reach many ground stations very far away. This is an aspect that sets the scenario apart from usual mobile ground networks analysis.
- **Aircraft RF shielding characteristics.** Several studies have shown that current commercial aircraft bodies do not ensure sufficient RF shielding. Although the materials used in the fuselage of today's aircraft are metallic, the windows allow for considerable leakage of radio signals. Literature and experience exist proving that it is possible for a terminal onboard existing aircraft to receive signals from Base Stations on the ground, to attach to the networks and even to start a call. Furthermore, theoretical simulations have shown that the combination of a leaky feeder along the cabin and the aircraft windows may act as an antenna array and thus have a gain in certain directions.
- **Re-use of GSM1800.** To be available for the vast majority of existing GSM mobile phones, the system will operate in the GSM1800 band. This means that it will re-use frequencies that are on use on the ground networks that the aircraft flies over, potentially causing in-band interference to both uplink and downlink of those systems.
- **Use of the Network Control Unit.** At switch-on, a User Equipment (UE) will attempt to connect to a network following rules set in 3GPP specifications and its particular implementation. It will perform a search for available networks over the multiple technologies and multiple bands that it supports. Depending on the handset's network selection rules, it will then try to decode the broadcast channels and to attach to the strongest cell, very likely transmitting at its highest power.

The NCU prevents this by means of a noise signal transmitted over the entire downlink bands of the mobile systems listed in the previous section. The unwanted effect of the NCU is the potential interference produced by the noise signal on the ground, not only in GSM1800 networks, but in all the networks that it is intended to screen.

- **Legal Status of the NCU.** A standalone NCU may be considered by some to be a radio jammer, and such equipment is deemed illegal under the R&TTE Directive as being designed to cause interference to GSM networks. However, the TCAM has considered that the NCU in conjunction with the pico Base Station have the opposite purpose, that is, to provide connectivity.

On this basis, and provided that it is designed so as it does not cause harmful interference to ground networks, the system falls into the domain of the Directive and can be marketed.

- **Multiple aircraft.** The effect of multiple interference sources cannot be neglected – some busy airports will have a significant number of commercial aircraft in their surroundings. For example, a typical busy-hour figure in London airspace is around 80 simultaneous aircraft above 3000 m and within 100 km radius. This scenario has been covered by the CEPT study.
- **Worst case of interference.** The relative position of the aircraft to the ground victim has great impact on the level of interference, and the worst case is not obvious to find. At a given altitude, the path loss determined by the distance, and the antenna pattern of the ground BTS, have opposite effects. The elevation angle at which the ground victim receiver sees the interfering aircraft changes as the aircraft flies, the worst-case elevation angles being in principle when the victim terminal is directly below the aircraft, or the victim base station is close to the horizon as seen from the aircraft. In addition, the radiation pattern of the aircraft is generally not isotropic.
- **Modern mobile systems can tolerate increased levels of in-band noise.** This is an inherent characteristic of a Wideband-CDMA system like UMTS, but advanced receivers in GSM terminals also provide interference cancellation. It is a field of ongoing work and enhanced performance of the terminal receivers is to be expected. This puts some constraints on the nature of the noise the NCU must generate, which must be of a type that the receivers will not be able to cancel.

In summary, the unwanted emissions from the system and the ground link that they impact are as follows:

- NCU emissions in the Terrestrial Downlink (base station transmit → mobile station receive link);
- Onboard BTS emissions in the Terrestrial Downlink (base station transmit → mobile station receive link), at 1800 MHz only;
- Onboard terminal emissions in the Terrestrial Uplink (mobile station transmit → base station receive link), (assuming only controlled mobiles are transmitting) at 1800 MHz only.

Assuming that a certain level of interference can be tolerated by ground mobile networks, and taking the propagation conditions as a parameter, it is possible to derive the maximum e.i.r.p.⁴ that an airborne point source can have without interfering with the ground. CEPT Project Team SE7 has performed this analysis and concluded on a set of limits, given at heights above ground from 3000m to 8000m. The limits are specified for the 1800MHz band for the onboard terminal and the pico BTS, and the 450MHz, 900MHz, 1800MHz and 2 GHz bands for the NCU. These are the theoretical limits defined outside the aircraft in order to avoid interfering with the

⁴ Effective Isotropic Radiated Power

ground systems under consideration: however proving conformance to those limits will be difficult in practice.

In addition, the onboard system has its own operating requirements in terms of power:

- The NCU must transmit at a level sufficient to effectively cover the signals from ground BTSs;
- The onboard pico base station needs to transmit at higher power than the NCU to avoid being interfered by it. This is the connectivity margin - the CEPT study assumed a value of 12 dB over the NCU level;
- The transmit power of the terminals will be nominally 0 dBm.

Based on the three parameters above, the e.i.r.p. limits and certain assumptions regarding the aircraft and the leaky feeder antenna, the CEPT SE7 report has concluded on a set of requirements for the effective attenuation of the aircraft.

The effective attenuation is the factor that relates the power radiated from the transmitters inside the aircraft (NCU, Base Station and user terminals) to the e.i.r.p. values outside the aircraft. It is a notoriously difficult parameter to assess and to measure: it depends on factors particular to each aircraft, such as hull attenuation, cabin characteristics and installation of the onboard leaky feeder or antennae.

A number of theoretical and practical studies of this factor were presented to CEPT SE7, showing a large spread of results. CEPT SE7 found it impossible to define a precise relationship, analytical or empirical, that could be applicable to a broad range of aircraft types and GSM onboard installations.

In conclusion, the operational requirements and the interference requirements put a limit to the range of utilization: the transmitted power of the NCU must be sufficient to cover the ground networks inside the cabin, but at the same time it must be low enough to avoid interference to their downlink. The onboard Base Station needs a few dB more than the NCU, but again it should not interfere at ground level. The emissions of onboard terminals, when set at 0 dB, should not interfere with the uplink of ground networks.

The minimum height above ground proposed by CEPT is 3000m, but if the aircraft attenuation with a given solution is not sufficient to avoid interference on the ground at this height, the CEPT Decision requires that the minimum height be increased.

There is, in summary, a trade-off between the attenuation and the minimum height of operation. It must be noted that it is in the interest of the system operators to comply with the requirements at the lowest minimum height (always over 3000m), since this will stretch the fraction of flight time during which the service can be provided.

ETSI's contribution to GSM onboard

Since it has to provide connectivity to any GSM terminal, the radio interface of the on-board system must follow the GSM specifications developed in 3GPP and ETSI⁵. Similarly, the A and Gb interfaces are those used in Public Land Mobile Networks (PLMN). The system is hence fully compliant with GSM as it is standardized in 3GPP and ETSI.

Although the work on co-existence has taken place in CEPT SE7, ETSI and 3GPP groups have played an important role in providing clarification of the specifications, guidance on the future developments, and comments and review of the work of SE7:

- ETSI MSG (Mobile Standards Group) has acted as the official point of contact between the CEPT groups and the 3GPP working groups for the onboard GSM work. It first reviewed the GSM onboard proposals in October 2004 and has since been the liaison group between 3GPP and CEPT.
- 3GPP GERAN Working Group (WG) 1 provides the GSM system radio aspects expertise. Since November 2004, it has discussed GSM onboard and contributed to SE7. GERAN WG1 has studied the interference to GSM networks and provided feedback on the parameters for the simulations. It has also advised regarding future developments of GSM, in particular the improvements in terminal receivers.
- 3GPP RAN WG4 provides the UMTS UTRAN radio aspects expertise. RAN WG4 has studied the impact of the system on WCDMA networks, reviewed the work of SE7 and provided parameters for the simulations.

ETSI is mandated by the European Commission to create the Harmonized Standards (HS) required to meet compliance to the R&TTE Directive. HSs provide technical requirements associated with the Essential Requirements of the Directive, and equipment which meets the relevant HS may be freely marketed in the European Union.

ETSI has already developed such a Harmonized Standard for GSM Base Stations and terminals [7] [8]. Given that TCAM has decided to put the NCU under the scope of the Directive, ETSI has the task of producing the associated HS. A joint ETSI MSG – ERM group was created in January 2006 for this assignment.

The HS will set RF requirements for the NCU and the Base Station at the antenna port, plus a few signalling requirements. However, given the relevance of the effective attenuation of the aircraft for this particular scenario, a Technical Specification (TS) will be produced along with the HS to lay out operational

⁵ Work on specifying GSM originated in CEPT and was subsequently transferred to ETSI. ETSI is a founding partner of 3GPP, the 3rd Generation Partnership Project, created to develop globally-applicable specifications for 3rd Generation mobile technologies. The task of maintaining and further developing GSM and the evolved technologies (such as EDGE and GPRS) has been transferred from ETSI to 3GPP.

requirements and provide guidance on the installation in order to show conformance of the system to the Technical Annex included in the CEPT Decision.

The HS will contain requirements such as:

- Accuracy of the transmitted power
- Adjacent channel leakage
- Spurious emissions
- Intermodulation
- Sensitivity
- NCU power in the protected bands
- NCU out of band emissions
- Implementation of the Mobile Station power control in the Base Station (signalling)

The HS and the TS will define a set of RF requirements, methods of measurement and installation guidelines covering the provisions of the R&TTE Directive and the ECC Decision. Compliance to these documents will ensure that the impact of the GSM onboard system on terrestrial networks remains tolerable.

Conclusions

It is now accepted that it is technically feasible to offer a GSM service on-board civilian aircraft that is safe in terms of avoidance of interaction with aircraft systems, immune from interference with terrestrial mobile communications, compatible with current regulation (at least that of Western Europe), and capable of offering a service that responds to perceived customer demand. In order to achieve these benefits, effective management of the on-board systems (including the passengers' mobile terminals) and of the air-ground links is imperative. It is in these areas primarily that technical standards from ETSI are making a significant contribution.

This White Paper has outlined work performed within ETSI, the European Commission and CEPT to find technical and regulatory solutions for GSMOB.

Naturally, there are issues related to the offering of GSMOB that extend beyond the purely technical and regulatory. There are social issues, such as how a system can be managed to prevent annoyance to other passengers. Cabin crew are likely to have to acquire new skills to deal with such circumstances, as well as for managing the use of the system in the various phases of the flight. With the support of the airlines and the GSMOB operators, passengers may need to be taught a new 'social etiquette' for the use of mobile devices in-flight.

The aviation industry will need to address issues of aircraft and system type approval, taking account of the wide variety of aircraft configurations to be accommodated.

There are also security issues beyond those of system interference, such as the potential for GSMOB to be exploited in terrorist situations. Operating procedures will need to be established by airlines and air regulators to address all these circumstances.

Finally, of course, GSMOB will only be deemed a success if it meets passengers' demands and satisfies the commercial expectations of its promoters.

These wider issues lie outside the scope of ETSI, whose contribution is limited to the technical specifications for GSMOB. Nevertheless, by building on the pedigree of the hugely successful GSM technology, whose specifications have been developed and evolved by ETSI over many years, there is a high level of confidence in this new venture.

Abbreviations

3GPP	3 rd Generation Partnership Project
AGS	Aircraft GSM Server
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CIDS	Cabin Intercommunication Data System
DCS1800	Digital Cellular System at 1800 MHz
ECC	Electronic Communications Committee
EDGE	Enhanced Data Rates for GSM Evolution
ERM	ETSI Technical Committee – Electromagnetic Compatibility and Radio Spectrum Matters
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FLASH-OFDM	Fast Low-latency Access with Seamless Handoff – OFDM
GERAN	GSM/EDGE Radio Access Network
GW	Ground Gateway
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMOB	GSM On-Board
HS	Harmonized Standard
Inmarsat	International Maritime Satellite
IP	Internet Protocol
MSC	Mobile Switching Centre
MSG	ETSI Mobile Standards Group
NCU	Network Control Unit
NOC	Network Operation Centre
O&M	Operation and Maintenance
OFDM	Orthogonal Frequency Division Multiple Access
PLMN	Public Land Mobile Network
PSTN	Public Switched Telephone Network
R&TTE	Radio & Telecommunications Terminal Equipment
RAN	Radio Access Network
RF	Radio Frequency
SE	Spectrum Engineering
SGSN	Serving GPRS Support Node
SMG	(Former ETSI) Special Mobile Group
SMS	Short Message Service
TCAM	Telecommunications Conformity Assessment and Market Surveillance Committee
TFTS	Terrestrial Flight Telecommunication System
TS	Technical Specification
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
VLR	Visitor Location Register
VMSC	Visited Mobile Switching Centre
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

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