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Resumen

Durante muchos años, la industria aeronáutica ha ido en busca de una tecnología que permitiera el servicio de comunicaciones móviles a bordo de las aeronaves con precios asequibles. Sin embargo, una serie de impedimentos técnicos dificultan el uso de la ya conocida red GSM con esta finalidad. Los terminales móviles a bordo radian con elevada potencia debido a la lejanía de las estaciones base terrenas, lo cual podría causar graves interferencias en los sistemas de aviónicos. Por otro lado, dada la alta frecuencia del handover generado entre células GSM, los terminales móviles a bordo podrían degradar el sistema terrestre debido a las grandes cantidades de señales de control requeridas. Para dar solución a los anteriores problemas, en 2005 surgió una solución tecnológica conocida como GSM on-board (GSMOB). El sistema GSMOB embarcado consiste en una estación base de baja potencia y una unidad asociada que emite ruido en las bandas de trabajo GSM. De esta forma se aumenta el nivel de ruido dentro de la aeronave por encima del nivel de señal procedente de las estaciones base terrenas, evitando así que los terminales puedan llegar a sincronizar dichas estaciones y favoreciendo que lo hagan con la estación base embarcada. El nivel de potencia radiado por los terminales móviles se ve reducido considerablemente al sincronizar con la estación a bordo y no con las terrenas.

El siguiente trabajo final de carrera pretende confeccionar un documento que proporcione una visión global del sistema GSMOB, el cual se está empezando a ofrecer comercialmente por importantes compañías aéreas en toda Europa. Además, no solo se han tratado los aspectos puramente técnicos sino también los relacionados con la normativa vigente y los procedimientos operativos asociados.

Title: GSM on board aircraft

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Overview

For several years the aircraft industry has been looking for a technology to provide at a reasonable cost a phone service onboard aircraft. Nevertheless, some technical hitches make successful calls via the terrestrial Global System for Mobile Communications (GSM) network impossible. The mobiles unable to make reliable contact with ground-based base stations, would transmit with maximum RF power and these RF fields could potentially cause interference with the aircraft communications systems. On the other hand, the high speed of the aircraft causes frequent handover from cell to cell, and in extreme cases could even cause degradation of terrestrial services due to the large amount of control signalling required in managing these handovers. In order to avoid these problems and allow airline passengers to use their own mobile terminals during certain stages of flight, a novel approach called GSM On-Board (GSMOB) was suggested in 2005. The GSMOB system consists on a low-power base station carried on board the aircraft itself, and an associated unit emitting radio noise in the GSM band, raising the noise floor above the signal level originated by ground base stations. Thus mobiles activated at cruising altitude do not see any terrestrial network signal, but only the aircraft-originated cell. This way, the power level needed is low, which reduces the interference with aircraft systems.

This thesis provides a general overview on GSMOB system, which is nowadays being offered commercially by several relevant European airlines. Moreover, other aspects beyond the purely technical such as operational and regulatory issues have been addressed.

GSM ON BOARD AIRCRAFT

Author: Carlos Gonzaga López
Supervisor: Lecturer Ari Rantala

December 15, 2008

To my family,
for your continued support and encouragement.

"I cannot understand why people are frightened by new ideas.
I am frightened of old ones."

John Cage.

Abstract

For several years the aircraft industry has been looking for a technology to provide at a reasonable cost a phone service onboard aircraft. Nevertheless, some technical hitches make successful calls via the terrestrial Global System for Mobile Communications (GSM) network impossible. The mobiles unable to make reliable contact with ground-based base stations, would transmit with maximum RF power and these RF fields could potentially cause interference with the aircraft communications systems. On the other hand, the high speed of the aircraft causes frequent handover from cell to cell, and in extreme cases could even cause degradation of terrestrial services due to the large amount of control signalling required in managing these handovers. In order to avoid these problems and allow airline passengers to use their own mobile terminals during certain stages of flight, a novel approach called GSM On-Board (GSMOB) was suggested in 2005. The GSMOB system consists on a low-power base station carried on board the aircraft itself, and an associated unit emitting radio noise in the GSM band, raising the noise floor above the signal level originated by ground base stations. Thus mobiles activated at cruising altitude do not see any terrestrial network signal, but only the aircraft-originated cell. This way, the power level needed is low, which reduces the inteference with arcraft systems.
This thesis provides a general overview on GSMOB system, which is nowadays being offered commercially by several relevant European airlines. Moreover, other aspects beyond the purely technical such as operational and regulatory issues have been addressed.

Abbreviation and Acronyms

ac-BTS Aircraft Base Transceiver Station

ac-MS Aircraft Mobile Station

AGS Aircraft GSM Server

BS Base Station

BTS Base Transceiver Station

CDMA Code Division Multiple Access

CEPT Conférence Européenne des Postes et des Télécommunications Administrations

CIDS Cabin Intercommunication Data System

CRI Certification Review Item

CSDU Cabin Satellite Data Unit

DLNA Diplexer/Low Noise Amplifier

EASA European Aviation Safety Agency

ECC European Communications Committee

EIRP Equivalent Isotropically Radiated Power

EMC Electromagnetic Compatibility

EMI Electromagnetic Interference

ETSI European Telecommunications Standards Institute

EUROCAE European Organization for Aviation Equipment

FAR Federal Aviation Regulations

FDD Frequency Division Duplex

FLASH Fast Low-latency Access with Seamless Handoff

GGW Ground Gateway

GPRS General Packet Radio Service

GSM Global System for Mobile Communications

GSMOB GSM On-Board

JAR Joint Aviation Requirement

LAN Local Area Network

MCL Minimum Coupling Loss

MS Mobile Station

MSC Mobile Services Switching Center

NCU Network Control Unit

OBCE On Board Control Equipment

OFDM Orthogonal Frequency Division Multiple Access

O&M Operations and Maintenance

PDA Personal Digital Assistant

PED Portable Electronic Device

RTCA Radio Technical Commitee for Aeronautics

R&TTE Radio and Telecommunications Terminal Equipment

SBB Swift Broadband system

SCM SDU Configuration Module

SEAMCAT Spectrum Engineering Advanced Monte-Carlo Analysis Tool

SGSN Serving GPRS Support Node

SITA Société Internationale de Télécommunications Aéronautiques

SMG (Former ETSI) Special Mobile Group

SMS Short Message Service

SNR Signal-to-Noise Ratio

TCAM Telecommunications Conformity Assessment and Market Surveillance Committee of the European Commission

TFTS Terrestrial Flight Telecommunication System

WLAN Wireless Local Area Network

UE User Equipment

ULTRA UMTS Terrestrial Radio Access

UMTS Universal Mobile Telecommunications System

VLR Visitor Location Register

WCDMA Wide Band CDMA

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First and foremost, I want to thank my supervisor Mr. Ari Rantala for allowing me to write this bachelor thesis at TAMK despite my background does not completely fit into his work camp. Writing this thesis about an unknown topic to me (at least in the beginning) has truly been an enriching experience.

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But this is not the end!

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A big embrace to my sister Ana. I am sure you will really become a good doctor.

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Carlos Gonzaga
December 2008

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Chapter 1

Introduction

Making air traveling more pleasant for passengers is a winning factor for airlines. Nowadays, people get more familiar with personalized equipment as Personal Digital Assistant (PDA), laptops or mobile phones. For several years the aircraft industry has looked for a technology to provide at a reasonable cost a phone service onboard aircraft. Unfortunately, It have not been possible to allow passengers to use their own mobile phones during the flight until not long ago, mainly due to both technological and legal matters. Since 1988 many studies have taken place to cover these requirements.

A first attempt to make this kind of service feasible in Europe was the Terrestrial Flight Telecommunication System (TFTS) [1], which 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 m) and reach higher levels (10000 m). However, commercial demand for TFTS failed to sustain initial expectations, 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. Consequently, this service ceased by 2002.

More recently, Boeing has been offering its *Connexion* service through selected airlines such as Lufthansa, Japan Airlines or Singapore Airlines. *Connexion* provided Internet access to travellers. The system used a satellite link to connect to the ground and a Wireless Local Area Network (WLAN) on board for the system access. Due to the lack of market demand and the high cost Boeing discontinued the service at the end of 2006 [2].

Many organizations have been looking at the possibility of supporting a

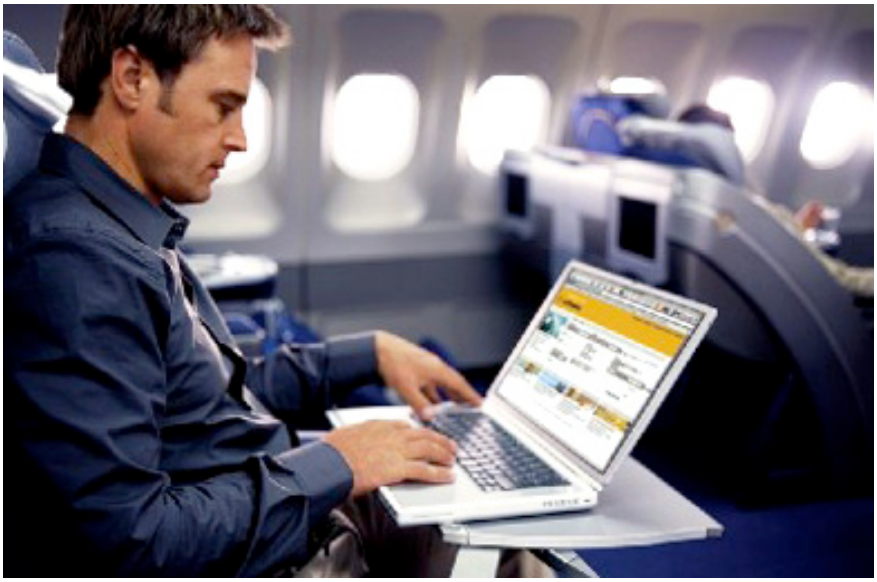

Figure 1.1. Sailing on the Internet through Boeing´s Connexion service. Extracted from [4].

Global System for Mobile Communications (GSM) service on aircraft. For instance, the European Telecommunications Standards Institute (ETSI) (Former ETSI) Special Mobile Group (SMG) committee studied this as long ago as 1988. Recently there has been more and more activity in this area since many companies are interested in offering GSMOB service as a feasible commercial venture. This system allows passengers to use their own mobile phones for voice and dataservices during dedicated phases of the flight. It does not include aircraft-specific phones, such as those integrated within the aircraft seat that are made available by some airlines, nor does it cover operational communications made by and to the aircraft's crew.

Airbus was first to receive airworthiness certification for a cell-phone system on board an aircraft, to certify that the system does not present a risk to the aircraft and its safe operation (cf. Section 6.3). On 18th June 2007, the European Aviation Safety Agency (EASA) approved the OnAir[1] GSMOB system for a specific airplane and for identical built aircrafts by issuing a specific Certification Review Item (CRI). This CRI addresses primarily safety objectives regarding the system description, but also the usages of passenger mobiles as an electromagnetic source onboard. Now this system is offered as an optional cabin system to customers and operators of the Single Aisle Aircraft Family (A318/A319/A320/A321).

[1]OnAir was formed in 2005 to develop and operate inflight passenger communications services. It is owned by Société Internationale de Télécommunications Aéronautiques (SITA) and Airbus

An important topic of the approval process was the demonstration of compliance for Electromagnetic Interference (EMI) compatibility of all installed aircraft systems. Until now, the potential disturbance to land-based mobile networks was one reason for prohibiting mobile phone use in planes. The other reason was the risk of high-power transmissions from mobile phones in aircraft interfering with on-board navigation and avionics equipment. This risk, already small, is made remote by the GSMOB service, which introduces a controlled environment inside the cabin as it is further explained in the following chapters.

It can be expected that the GSMOB service becomes as popular as it is on the ground. The user experience will be personalized and the system will work much the same like international roaming works: same terminal, same agenda and, presumably, a pricing scheme similar to that for international calling. Taking into account these key differences, GSMOB will likely succeed where TFTS and *Connexion* failed.

Although at present the service is limited to GSM technology, other mobile technologies such as 3G could also be deployed in the future, depending on market demand.

Air France was the first airline in the world to offer an in-flight mobile phone service on international flights [3]. Emirates, the largest airline in the Mideast, has already equipped an Airbus A340 fight from Dubai to Casablanca with mobile technology and intends to extend the service to its entire fleet over the next months. Ryanair, the popular low-cost European airline, is planning to offer in-flight calls, anticipating potentially lucrative profits from the service.

On the other hand, and leaving aside the technical aspects, another more ethical issue to take into consideration is whether the airlines will confront a backlash among passengers who simply want a quiet flight. For that reason, Lufthansa, Europe´s second-largest airline, has said it will not offer the service, after travelers made clear their contempt.

Chapter 2

Description of the service

GSMOB service allow passengers to use their own mobile terminals during certain stages of flight. Passengers are able to make and receive calls, send and receive Short Message Service (SMS) and use General Packet Radio Service (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).
- Emissions at higher frequencies present higher path loss.

These characteristics make it easier to avoid interference to the ground systems as explained in Chapter 4. In addition, the majority of multi-band GSM units support the 1800 MHz band.

The Figure 2.1 shows the functional overview of the system. The terminals connect to an onboard pico Base Station (BS) using the standard GSM radio interface. The onboard cell is connected to the terrestrial networks through a satellite link.

GSMOB works in aircraft flying over terrestrial networks, very often over more than one country. The system must ensure that onboard terminals do not

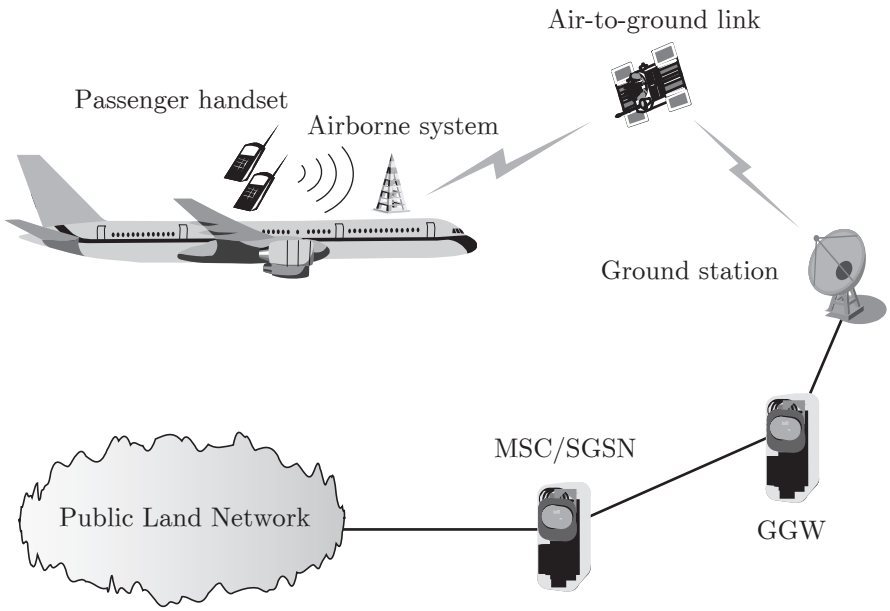

Figure 2.1. Functional overview of the GSMOB system.

attempt to communicate or interfere with terrestrial networks, and the system itself must not interfere or attempt to communicate with ground terminals

The major challenge with respect to safe operation of the GSMOB system is to control radio emissions of both, the mobile phones brought into the aircraft by passengers, called Aircraft Mobile Stations (ac-MSs) from now on, and the onboard transmitters. ac-MSs tend to log into compatible terrestrial cellular networks when left ON even at cruising altitudes of 10,000 m and above [5]. In these cases mobile phones generally transmit at relatively high power levels (up to 2 W).

The log-on procedure used by all mobile phones on the market today is depicted in Figure 2.2 below. This general procedure is independent on the cellular standard (e.g. GSM, Code Division Multiple Access (CDMA), Wide Band CDMA (WCDMA)) supported by the mobile phone.

In general a mobile phone will after power ON try to physically synchronize to a base station by receiving its synchronization or pilot channel. If a network is not present, the mobile phone will continuously monitor its receive bands until either its battery is empty or it is switched OFF. Note, that no transmission takes place in this case.

If the mobile phone successfully detects a synchronization or pilot channel, it will establish physical synchronization to the base station. In a second step the mobile phone will scan for the associated broadcast channel, which carries the

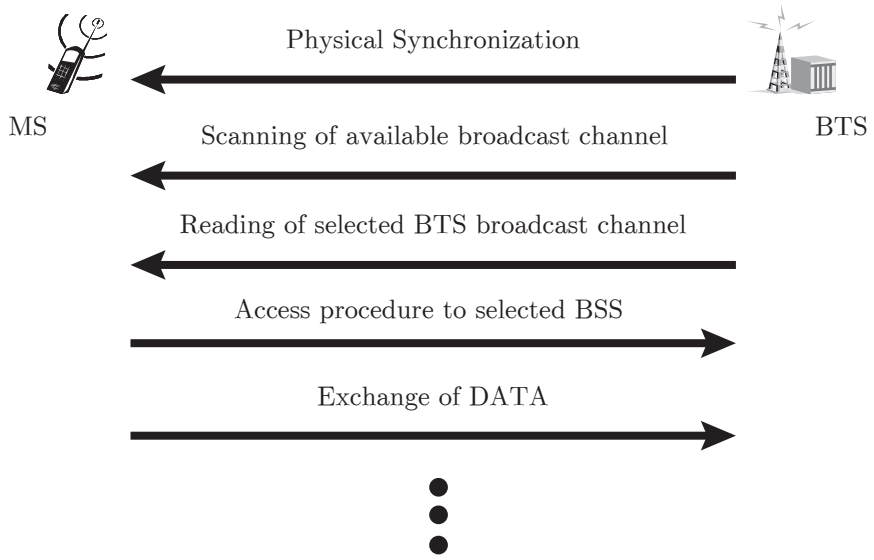

Figure 2.2. Log-on procedure for mobile phone systems.

system information (e.g. network identity, frequency allocation, etc.).

After these two steps have been successfully taken, the mobile phone is able to perform an "access request" to request the establishment of a signaling channel in order to register to the network. After the channel has been established data can be exchanged.

A well-known and thoroughly studied technical approach for controlling radio emissions of passenger mobile phones aboard aircrafts is to use a NCU. The aim of the NCU is to prevent ac-MSs to synchronize and attach to terrestrial cellular networks. This is usually achieved by injecting wideband noise of low power density into the relevant frequency bands, by which signals from terrestrial cellular networks are effectively screened.

Thus, these networks are invisible for ac-MSs and they will not be able to synchronize and attach to on-ground networks and hence, will not be able to transmit at all. Only those mobile phones capable of connecting to the Aircraft Base Transceiver Station (ac-BTS) will be able to transmit in a controlled manner.

The NCU is therefore a crucial part of the overall GSMOB system. Moreover, ac-MSs, when attached to the ac-BTS, will be forced to operate at the lowest possible power level. The actual power levels of the onboard system require a careful balance between the band-specific levels of noise injected by the NCU to ensure all mobiles do not attempt to connect to terrestrial networks and the maximum permitted transmission power.

Details of the overall architecture and all components of the GSMOB system can be found in Chapter 3.

The operational states of the GSMOB system are fully controlled automatically. E.g., during takeoff, climb, descent, approach and landing the ac-BTS, the NCU as well as all ac-MSs will be switched OFF in order not to interfere with terrestrial mobile phone systems on ground. For this purpose, an aircraft computer periodically sends the current altitude, position and flight phase to the GSMOB system.

Furthermore, the GSMOB system is connected to the Cabin by the Cabin Intercommunication Data System (CIDS), in order to inform passengers when use of mobile phones is allowed and when they must be switched OFF. For this purpose specific means, e.g. "NO MOBILES" signs are introduced which replace the "NON SMOKING" signs above the seats. Permanently "NON SMOKING" signs will be installed insead. Further details, on the operational procedures of the GSMOB system can be found in Chapter 6 of this contribution.

Chapter 3

GSMOB system architecture

This Chapter focuses on one possible implementation of a GSMOB system, but other possible implementations could be deployed by operators in order to achieve GSM coverage of an aircraft.

The complete GSMOB system including terrestrial elements typically consists of an airborne and a ground segment, subdivided in two domains, as shown in Figure 3.1.

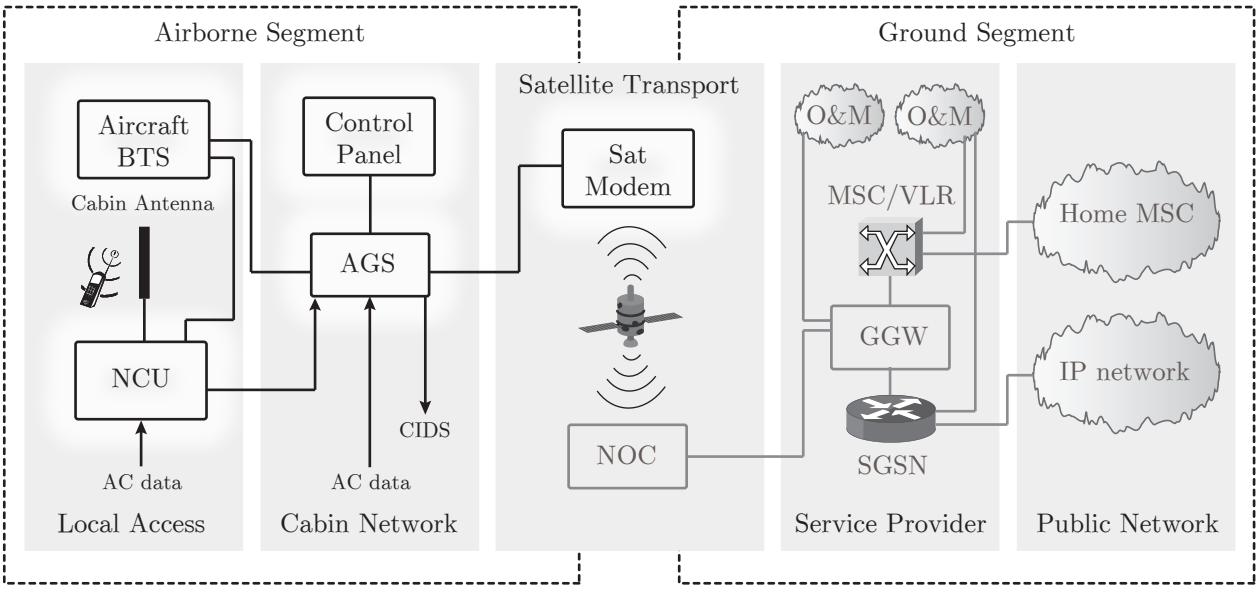

Figure 3.1. Overall end-to-end architecture of a complete GSMOB system.

3.1 Ground Segment

The Ground Segment consists of the *Service Provider Domain* and the *Public Network Domain*:

- By means of the Service Provider Domain, the communication controller functions that act together with the AGS functions in the aircraft are hosted. For this purpose, a Ground Gateway (GGW), and GSM visited network components such as Mobile Services Switching Center (MSC)/Visitor Location Register (VLR) and Serving GPRS Support Node (SGSN) are required. Their main features are to perform the routing towards the aircraft, and to connect the aircraft traffic with terrestrial backbone networks of the Public Network Domain. The Service Provider Domain must host accounting and billing functions, mobility management, and routing capabilities.

- The Public Network Domain provides the interconnection of the call, data or signalling communication to the relevant public network end points.

To go into details of the Ground Segment and their components are not the focus of this review.

3.2 Airborne Segment

The Airborne Segment consists of the *Local Access Domain* and the *Cabin Network Domain*:

- The Local Access Domain contains the ac-BTS providing GSM access for passengers' ac-MSs and the NCU. The purpose of the NCU in conjunction with the GSM pico-cell is to prevent ac-MSs from accessing terrestrial networks and to control the radio frequency emissions of all ac-MSs transmitting in GSM and WCDMA/Universal Mobile Telecommunications System (UMTS) in both 900 MHz and 1800 Mhz bands, WCDMA/UMTS in 2 GHz band and CDMA in 450 MHz band.

- The Cabin Network Domain contains the control panel and an AGS. The AGS integrates the GSM software on-board (e.g. base station controller functionality) and interconnects the mobile phone system with the satellite modem. The AGS furthermore provides the interfaces for receiving flight

data as well as for providing the required signals to the CIDS. The control panel allows the crew to control the operational states of the GSMOB system.

Note that in this system description only the elements related to the GSMOB are detailed. It does not include aircraft systems, such as the avionics, as these are out of scope of this thesis.

A fifth domain called *Satellite Transport Domain* connects the two segments. The satellite link provides the transportation and interconnection to terrestrial service providers and backbone networks. This domain is not part of the GSMOB system. The first GSMOB system deployed uses the *Inmarsat* Swift Broadband system (SBB).

3.3 System Components

The following describes the main components of the GSMOB system, focusing on the Airborne Segment only, as just this part of the system is relevant regarding airworthiness, human health and telecom regulatory considerations.

3.3.1 Cabin Antennas

The cabin antennas are used to transmit and receive the RF signals within the cabin. The ac-BTS and NCU share the same antenna.

The antenna is typically a leaky line antenna. A leaky line antenna is essentially a coaxial cable, which has apertures in its shielding through which RF signals are radiated. This coaxial cable is installed above the ceiling panels along the whole aircraft cabin as showed in Figure 3.2

If the installation design of the leaky line antenna is carried out properly, then it is possible to control the radiated field accurately. The leaky line antenna provides a uniform linear coverage of the aircraft cabin at very low radiation power levels by propagating the RF signal via the cable. Therefore, exposure to electromagnetic radiation of aircraft equipment, crew and passengers will be very low (e.g. less then 1% of already introduced Wireless WLAN servises within aircrafts). Furthermore, this antenna type supports a wide frequency band, which is required for injecting the wideband noise signals generated by the NCU. For reception a passive dipole antenna can be used.

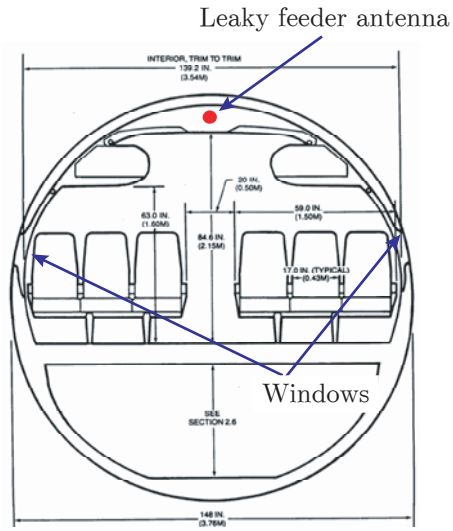

Figure 3.2. Typical leaky line antenna installation in a narrow body aircraft. Extracted from [5].

Airbus internal tests in single aisles and long-range aircrafts have shown that no aircraft system is impacted by the RF signals emitted by the leaky line. The latest status of the work can be enquired within [7].

3.3.2 Aircraft Mobile Station

The ac-MSs are the onboard mobile terminals able to operate with the ac-BTS. These passenger-owned mobile phones have the following characteristics:

- They are not considered as part of the GSMOB system according to the GSM-1800 standard.
- GSM access in the 1800 MHz frequency bands for communication.
- Non-compliant phones to the GSM standard in the 1800 MHz band are prevented from transmitting via the NCU
- Nominal radiated power (uplink) set to the minimum possible power level, e.g. 0 dBm.

In order to keep ac-MSs emissions as low as possible, the ac-MSs transmission power is controlled to its minimum power level by the ac-BTS.

Link budget calculations show, that the minimum nominal power level specified for a GSM-1800 compliant ac-MS is sufficient for successful communication between the ac-MS and the ac-BTS.

It is understood that for operating of intentionally transmitting Portable Electronic Devices (PEDs), such as mobile phones, inside the aircraft cabin, relevant airworthiness standards apply, currently under development with European Organization for Aviation Equipment (EUROCAE) [7] and Radio Technical Commitee for Aeronautics (RTCA) [8].

3.3.3 Network Control Unit

The NCU is an essential part of the GSMOB system. This part of the system is designed to ensure that ac-MSs within the cabin can not access terrestrial networks and that they do not transmit any signal without being controlled by the GSMOB system. These access attempts would usually cause the mobile phone to transmit at much higher power level as that used for regular communication.

The NCU works injecting broadband noise into the relevant frequency bands in which mobile phones are operated. Thus only mobile phones compatible with GSM- 1800 will be able to transmit any signal while being controlled by the GSMOB system via standard GSM power control mechanisms

While there are other approaches to solve this problem, raising the noise floor in the relevant frequency bands is a very simple, effective, futureproof and well studied approach. In special, the first system developed by Airbus [9] uses this approach.

The NCU is assumed to have the following key characteristics:

- The signal generated is a band-limited noise.
- The terrestrial cellular bands and technologies required to be controlled will depend on where the aircraft flies. E.g. for Europe the relevant frequencies and technologies will be within the following GSM and UMTS BTS/NodeB-to-Mobile Station (MS)/User Equipment (UE) (downlink) bands:
  - GSM and WCDMA/UMTS-900 (921-960 MHz).
  - GSM and WCDMA/UMTS-1800 (1805-1880 MHz).
  - UMTS ULTRA-FDD 2 GHz (2110-2170 MHz).

Figure 3.3 shows the spectrum of a noise signal generated by the NCU. In this example the 900 MHz, 1800 MHz and 2 GHz frequency bands are screened.

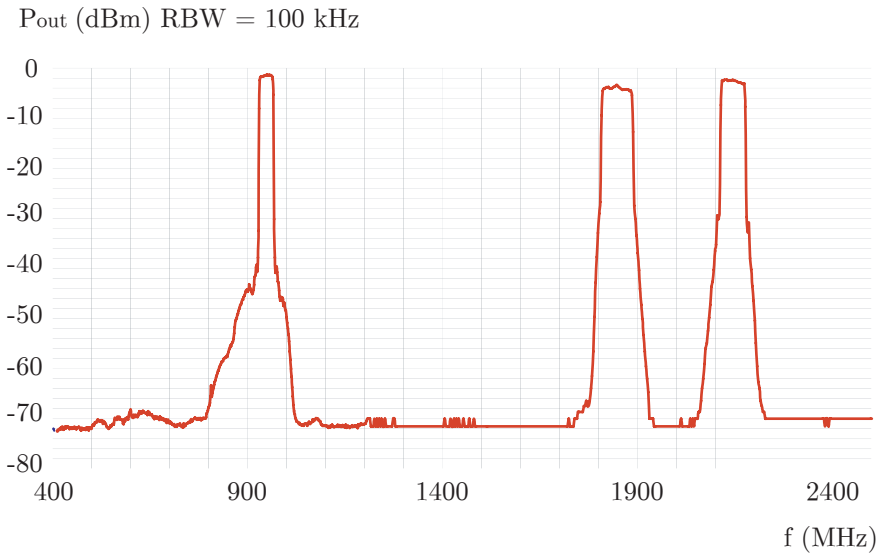

Figure 3.3. Example spectrum of the noise signal generated by the NCU [5].

- Power levels of the NCU may be reduced with increasing altitude because of the decreased signal strength received from terrestrial networks inside the aircraft.
- Transmission of band-limited noise signals is kept at power levels as low as possible. The power levels are dependant on the flight altitude and are set such that signals from terrestrial networks are effectively screened inside the aircraft.
- The transmission is stopped whenever the aircraft's altitude is below 3000 m above ground, operational procedures ensure that all active communications between ac-BTS and ac-MSs are stopped prior to shutting down the NCU. Further information about operation procedures can be enquired in Chapter 6.

3.3.4 Airborne GSM Server

The AGS is the central control subsystem of the GSMOB system, and is in charge of handling the transmission and reception of the data streams between the ac-

BTS and the ground.

The AGS manages the satellite link communication, controls the ac-BTS, monitors the NCU output power level and manages the Operations and Maintenance (O&M) functions.

The AGS provides also the interfaces to the aircraft internal systems for retrieving relevant flight information (e.g. actual position, altitude and flight phase) as well as for controlling passenger signs.

It furthermore hosts a database with geographical data, which is used to derive the altitude over ground and any location-specific system settings.

3.3.5 Aircraft Base Transceiver Station

The GSMOB connectivity component is the ac-BTS, which provides the communication access to the ac-MSs and supports all necessary system features like radio access and radio resource management.

Since the NCU transmits contiguously across the whole band, the ac-BTS will have to transmit at a higher power level per channel.

The ac-BTS is assumed to have the following key characteristics:

- Support of standard GSM and GPRS services;
- Operating in the 1800 MHz frequency band over Europe: 1710-1785 MHz (Uplink) and 1805-1880 MHz (Downlink).
- Operating at a sufficient power level (at least 9 dB over the NCU power level per channel).
- The Max. transmit power level (at ac-BTS output port) has been established at 23 dBm[1]

3.3.6 Control Panel

The control panel is used as an interface by the cabin crew to manually access the GSMOB system control and monitoring functions.

[1] An additional attenuation of approximately 25 dB has to be taken into account for leaky line antenna and RF combiners (required for operation of ac-BTS and NCU over the same leaky line antenna) resulting in an effective transmission power in the order of 0 dBm.

The control panel displays relevant system information, including the status indication (ON/OFF, major or minor failure). Furthermore, it provides the push buttons to activate and deactivate the "NO MOBILES" signs, as well as to activate and deactivate the "night mode".

"Night mode" consists in that only data and text-based services such as GPRS or SMS are possible, while all voice services are prevented, to create recovery periods during which passengers are able to sleep undisturbed.

3.3.7 Cockpit Button

The cockpit button is installed for the flight crew in an overhead panel, reachable for both, pilot and first officer. This push button gives the cockpit crew a final control over the system in the cabin.

The cabin crew can only activate the mobile telephony service when the cockpit button is activated.

A detailed example of a commercial GSMOB system is shown in Figure 3.4.

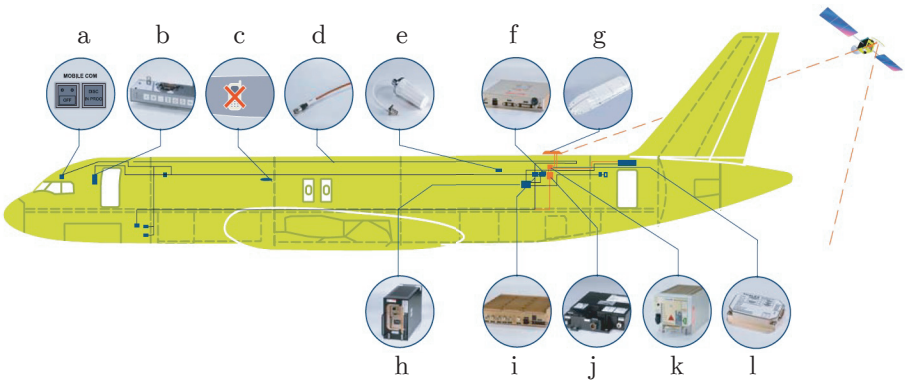

Figure 3.4. Example of an Airbus 320 family GSMOB System Installation [6]. a) GSM OFF Cockpit Switch. b) Attendants Control Panel. c) Independent PSC Signs: GSM OFF. d) Leaky Line Antenna. e) Reception Antenna. f) BTS. g) Intermediate Gain Antenna. h) AGS. i) OBCE. j) DLNA. k) DLNA. l) SCM.

Chapter 4

Compatibility with terrestrial networks

One of the main problems to be solved in GSMOB system is that an aircraft is not a Faraday Cage: as such it cannot prevent the reception of the terrestrial networks and therefore could damage the use of the terrestrial networks by creating interference on the Random Access Channel.

The Spectrum Engineering Working Group of the European Communications Committee (ECC), a committee of the CEPT, has carried out a large amount of work to study interference effects between a GSMOB system and terrestrial cellular networks. The results of this work are presented in [5]. This report serves as the technical justification for the formal decision on a harmonized use of the GSMOB system in the GSM-1800 MHz frequency band within Europe [10].

The telecommunication regulatory limits of the GSMOB system is defined in the technical annex of the decision [10] which has been based on the work done in the ECC Report 93 [5].

A large spectrum of interference situations have been defined and analyzed in ECC Report 93 [5], as well as various aspects such as the visibility of terrestrial networks for mobile phones aboard the aircraft and their ability to successfully access these terrestrial cellular networks.

Moreover, analysis has been carried out on the potential ability of the NCU and ac-BTS transmission to interfere with the downlink transmission of terrestrial cellular networks, for both a single and multiple GSMOB interfering links.

Finally, the impact of ac-MS transmission on the uplink transmission of

terrestrial cellular networks for single and multiple GSMOB interfering links has been analyzed.

For carrying out the investigations the methods of Minimum Coupling Loss (MCL) and Monte-Carlo[1] simulations were used to derive worst-case and typical results, respectively. The Monte-Carlo analysis takes into account random distribution of aircraft around a terrestrial station. For all the interference scenarios, the free space propagation model was used between the aircraft and terrestrial networks. Inside the cabin, a leaky feeder antenna was assumed to be used in the GSMOB system.

The GSMOB system considered in the report consists of a NCU, to ensure that signals transmitted by terrestrial mobile systems are not visible within the cabin, and an ac-BTS to provide connectivity. Combined they are designed to ensure that the ac-MSs only transmit at the minimum level of 0 dBm nominal value with a 0 dBi antenna gain.

The studies have considered both the reference values of network equipment parameters (extracted from the standards) as well as typical values, whenever available (as provided by manufacturers and operators). The conclusions of the report are based on typical values of network parameters.

In all interference scenarios the cellular standards as indicated next have been considered:

- GSM900
- GSM1800
- UMTS900
- UMTS1800
- UMTS ULTRA-FDD 2 GHz
- CDMA-450/FLASH-OFDM

[1]Using the Spectrum Engineering Advanced Monte-Carlo Analysis Tool (SEAMCAT), developed for compatibility studies within Conférence Européenne des Postes et des Télécommunications Administrations (CEPT)

4.1 Summary on the ECC Report 93 results and conclusions

The ECC Report 93 [5] report describes the studies developed on the compatibility of a GSMOB with terrestrial networks, when the aircraft is at least 3000 m above ground due to both operational and technical reasons. This minimum working altitude was proposed at first by CEPT, but if the aircraft attenuation with a given solution is not sufficient to avoid interference on the ground at this altitude, the CEPT might require the minimum working altitude to be increased.

The studies demonstrated that harmful interference to terrestrial networks will not occur provided that the following technical conditions are met:

- The transmit power of ac-MSs must be controlled by the GSMOB system to the minimum value (0 dBm nominal).
- ac-MSs/UEs not connected to the GSMOB system must be prevented from attempting to connect to terrestrial networks (in both the GSM1800 band and other relevant bands), as this would disrupt the operation of these networks and cause interference to them.
- The aircraft fuselage will attenuate the total power entering or leaking from the cabin, but it might under some circumstances also act as a directive radiator. If the cabin fuselage does not provide sufficient attenuation, an active device such as an NCU must be used to mask the signals from terrestrial networks that enter the cabin. The power of the masking signal from the NCU must be sufficient to reliably perform this function, but must not be high enough to cause harmful interference to terrestrial networks in any of the frequency bands in which the NCU operates.

if these conditions are not met, the signal strength onboard the aircraft received from terrestrial networks can be high enough for an ac-MSs/UEs to attempt connecting to a terrestrial network, even when an aircraft is at a high cruising altitude (10000 m above ground).

Both the level of GSMOB interference to terrestrial networks as well as the level of signals received from the ground by the ac-MSs/UEs are strongly dependent on the next factors:

- The height of the aircraft above ground.
- The average attenuation due to the aircraft.

- The directivity of the aircraft fuselage acting as an antenna.

The studies indicate that there is a need for fine balance between NCU transmitting at the power sufficient to remove visibility of the terrestrial networks and provide connectivity for GSMOB, whilst not being too high so as to cause harmful interference to terrestrial networks.

In order to avoid harmful interference to terrestrial networks (using the criterion $\frac{I}{N} \leqslant -6$ dB), the Equivalent Isotropically Radiated Power (EIRP) per channel of the signals radiated outside the aircraft by the GSMOB system and the ac-MSs, should not exceed the values showed in Table 4.1.

The values in Table 4.1 have been derived using the following assumptions:

- Characteristics of the terrestrial base station antennas are based on the Recommendation ITU-R F.1336-1 patterns and values commonly used in deployed terrestrial networks. Antenna gain and patterns are estimated to be representative of antennas in existing GSM or UMTS networks.
- Characteristics of the GSM1800 base stations and terminals are based on typical performance of state-of-the-art equipment (based on data supplied by mobile operators) for the stringent case of a noise-limited network.
- The EIRP outside the aircraft, of GSMOB entities inside the aircraft depends on the following characteristics:
  - The leaky feeder antenna.
  - The input power to the leaky feeder antenna.
  - The effective signal attenuation due to the aircraft.

The studies have proved that there is no significant increase in interference due to GSMOB emissions from multiple aircraft because:

- The dominant source of interference to a terminal on the ground is the GSMOB just in the closest aircraft.
- The ac-BTSs in different aircraft can operate on different frequencies, since sufficient available spectrum has been provided.

Table 4.2 shows minimum required effective attenuation due to the aircraft, using a cylinder model assuming a leaky feeder for ac-BTS/NCU.

Minimum operational height above ground	Maximum permitted EIRP produced by ac-MS, defined outside the aircraft (dBm/ 200 kHz)	Maximum permitted EIRP produced by NCU/aircraft-BTS, defined outside the aircraft in dBm / channel, with victim receiver directly below aircraft						
		Ac-BTS	NCU					
		1800 MHz (dBm/ 200 kHz)	450 MHz (dBm / 1250 kHz)	900 MHz (dBm / 200 kHz)	900 MHz (dBm / 3840 kHz)	1800 MHz (dBm / 200 kHz)	1800 MHz (dBm / 3840 kHz)	2000 MHz (dBm / 3840 kHz)
3000	-3.3	-13.0	-17.0	-19.0	-6.0	-13.0	0.0	1.0
4000	-1.1	-10.5	-14.5	-16.5	-3.5	-10.5	2.5	3.5
5000	0.5	-8.5	-12.6	-14.5	-1.5	-8.5	4.5	5.4
6000	1.8	-6.9	-11.0	-12.9	0.0	-6.9	6.1	7.0
7000	2.9	-5.6	-9.6	-11.6	1.4	-5.6	7.4	8.3
8000	3.8	-4.4	-8.5	-10.5	2.5	-4.4	8.6	9.5

Table 4.1. Maximum permitted EIRP of GSMOB emitting entities, defined outside the aircraft (dBm/channel) [5]

Minimum height above ground (m)	Minimum required effective attenuation of signals to and from the ac-MS (dB)	Minimum required effective attenuation of the signals from sources transmitting from a radiating cable				
		Ac-BTS	NCU			
		1800 MHz (dB)	450 MHz (dB)	900 MHz (dB)	1800 MHz (dB)	2000 MHz (dB)
3000	3.3	10.6	16.5	6.8	0.0	0.0
4000	1.1	8.1	13.8	4.1	0.0	0.0
5000	0.0	5.6	11.1	1.4	0.0	0.0
6000	0.0	2.7	7.9	0.0	0.0	0.0
7000	0.0	0.3	5.4	0.0	0.0	0.0
8000	0.0	0	5.5	0.0	0.0	0.0

Table 4.2. Minimum required effective attenuation due to the aircraft for GSMOB emitting entities, assuming leaky feeder solution and maximum radiation at 37 degrees below the horizontal plane [5]

Figure 4.1 shows the far-field antenna pattern elevation and azimuth cuts derived from one theoretical study. According to these cuts, the energy leaking through a single window (not obstructed by the wing) was found to have a peak aperture gain of 13.5 dB at 1920 MHz relative to an isotropic source. The location of this beam peak is directly abeam of the aircraft at an elevation of 37 degrees below the horizontal plane.

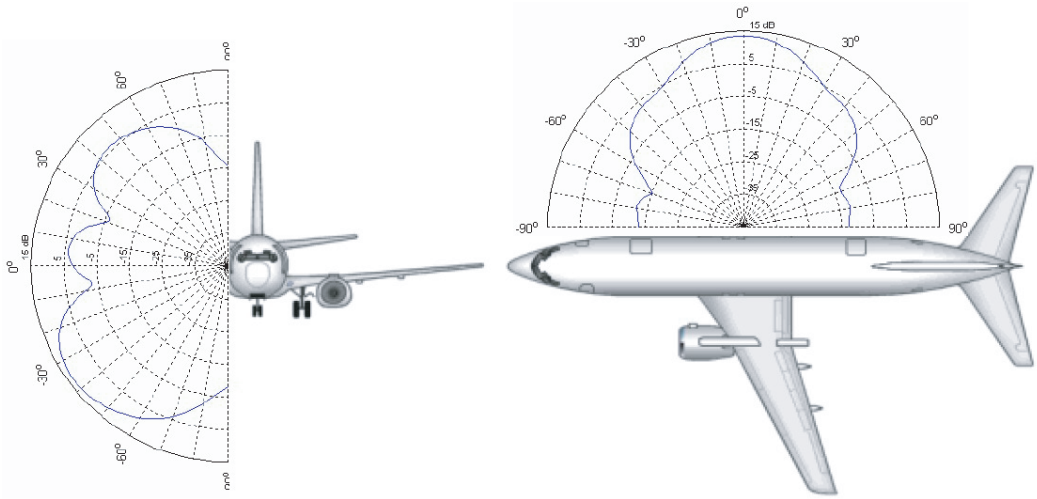

Figure 4.1. Elevation and azimuth patterns for a single aircraft window coherently illuminated by an isotropic source.

The required effective attenuation due to the aircraft describes proportion of total power leaking from (or entering) the cabin, and is a function of the relative fuselage gain in the direction under consideration, and the effect of any mitigating factors.

In order to avoid GSMOB system to cause harmful interference to terrestrial networks, the effective attenuation due to the aircraft must not be less than the minimum values in the Table 4.2, for the minimum flight level at which the system can be operated[2]. The values were derived for a single wide body aircraft which is the most critical case.

The attenuation due to the aircraft is a crucial factor for compatibility of GSMOB system. The ECC Report 93 [5] report describes a number of theoretical and practical studies of the isolation of the aircraft cabin for signals entering or leaving.

[2]Where the results of the calculation are negative, these have been replaced by zero, indicating that no effective attenuation is required to prevent interference for operation at that level above ground.

The large spreads of results found in the studies, may be caused by several factors:

- There is evidence that different types of aircraft have different isolation characteristics.
- The leakage of signals from the ac-BTS/NCU are likely to be directional. For example, if a leaky feeder is installed in the cabin roof, the radiation will be highest at an angle below the horizontal plane as shown in Figure 4.1.
- Some studies suggest that the aircraft can under some circumstances behave as a highly directional antenna. This effect can only be measured in the "far field", which is several Km away from the antenna. It is difficult to fully characterise the leakage from the aircraft by measurements made with the aircraft on the ground.
- The signal strength received by the ac-MSs/UEs from terrestrial networks is dependent on the location of the user inside the aircraft cabin and how the terminal is held.
- The movement of the aircraft and the directional properties of the cabin isolation can lead to a rapid time-variation of signal strengths.

Therefore, it is not possible to define a single typical value or angular distribution for cabin isolation.

In short, the ECC Report 93 [5] report defines the conditions under which GSMOB systems can be operated when more than 3000 m above ground level, resulting in no more than 1 dB increase of the noise floor in terrestrial network receivers. This prevents harmful interference to terrestrial networks (either in GSM1800 band or in other bands in which the NCU operates), provided that care is taken over the installation and operation of the GSMOB system.

Chapter 5

Operational issues

In this Chapter, an overview on the operational procedures for a safe operation of the GSMOB system is described.

The operational states of the GSMOB system in relation to the flight phases are shown in Figure 5.1 .

When the aircraft's main power bus is powered up, the GSMOB system enters the 'IDLE' state. This state means that the components are in stand-by. The AGS and NCU continuously evaluate flight data, such as actual position, altitude and flight phase, which they receive from the aircrafts' flight computer. Neither the NCU nor the ac-BTS are actively transmitting at this stage.

During the ground phases of the flight such as on gate or 'Taxing Out', the PAX signs 'NO MOBILES' are switched ON which indicates that the use of mobile phones is not allowed. The 'NO MOBILES' sign will remain illuminated during the 'Take-Off' and Climb phase.

The system becomes operational as soon as all of the following five conditions hold true:

1. The aircraft is in 'Cruise' phase.
2. The aircraft's altitude is at least 10000 ft (3000 m) above the ground level.
3. Operation of the GSMOB system is allowed according to telecom regulatory authorization (e.g. frequency allocation and use for that country is permitted).
4. The system status is not faulty (this includes the availability of the SAT-link).

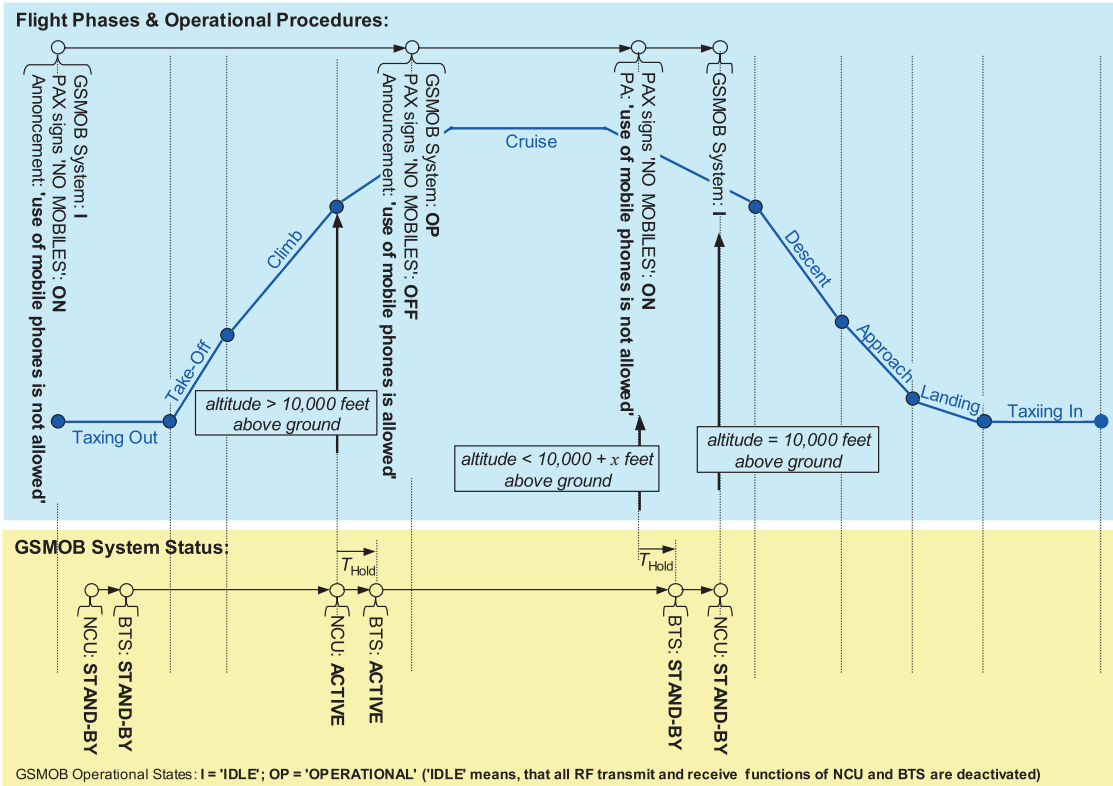

Figure 5.1. Flight phases, operational procedures and system states for the GSMOB system. Extracted from [12].

5. The cockpit and control panel switch are activated (ON).

At first the NCU's transmission power levels for the various supported frequency bands are set according to the actual altitude, and its transmitter is activated. If the AGS indicates that the NCU is working properly and some holding time has elapsed, the ac-BTS transceiver will be activated to enable communication with the ac-MS.

When all system components work properly, the PAX signs 'NO MOBILES' are switched OFF and a crew announcement to the passengers indicates that the use of mobile phones is allowed. In normal flight situations the GSMOB system remains in this state.

Nevertheless, if the pilot or cabin crew decide, for whatever reason, to restrict the usage of the system they are able to do it by deactivating the system via the cockpit switch or the control panel, respectively.

Furthermore, the crew is able to activate the 'night mode' in which voice call requests are rejected and only data and text-based services (e.g. GPRS and

SMS) are supported by the GSMOB system.

When the aircraft's altitude falls below $10000 + x$ ft above ground level, where x is a configurable margin, the PAX signs 'NO MOBILES' are switched ON and a crew announcement to the passengers indicates that usage of mobile phones is not allowed again. After a holding time, which allows passengers to terminate their ongoing phone calls, all active data and voice connections are terminated. Then the ac-BTS is set to stand-by by deactivating its transceiver.

When the descending phase starts and the aircraft's altitude is about 10000 ft above ground level, a trigger is generated which sets the NCU into stand-by by deactivating its transmitter. At this point the GSMOB system has returned to 'IDLE' state.

Chapter 6

GSMOB Systems Regulatory Background

6.1 ECC decision

Based on ECC Report 93 [5], ECC finally approved the harmonized use of GSMOB systems in the frequency bands 1710-1785 and 1805-1880 MHz.

The Decision [10], which was published in December 2006, will allow operation of a GSMOB 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 Radio and Telecommunications Terminal Equipment (R&TTE) Directive.

The R&TTE Directive establishes the regulatory framework for free circulation and operation of radio equipment and telecommunications terminal equipment within the member states of the European Union and thus states the legal objectives to be met by such equipment.

The Telecommunications Conformity Assessment and Market Surveillance Committee of the European Commission (TCAM) has stated that the GSMOB system elements are legally covered by the directive and its mechanisms should be used to determine the requirements to place them on the market. The TCAM provides assistance in the management of the R&TTE (Directive 99/5/EC).

Note that neither ECC Report 93 [5] nor the ECC Decision paper [10] or its technical annex do state anything about airworthiness aspects associated with

the operation of a GSMOB system and ECC does not intend to do so. The airworthiness certification is subject to the procedures and standards developed by the concerned aviation safety organizations.

6.2 Electromagnetic Radiation and Human Health

The European research project "WirelessCabin" [13] conducted a study on potential health impacts of mobile telephone systems on board. It concludes that this kind of systems, like the GSMOB, is safe concerning human health.

6.3 Airworthiness Certification Aspects

According to current regulations, the use of PEDs is only allowed during certain flight phases if their operation does not adversely affect the performance of the aircraft's systems and equipment (cf. JAR OPS 1.110 and FAR 91.21).

Cellular phones are classified as intentionally transmitting devices T-PED and hence, are currently not allowed to be used during any flight phase (cf. OPS Leaflet No. 29). EUROCAE WG58 and RTCA SC202 are currently working on general guidelines for the use of PEDs and T-PEDs on-board aircrafts. EUROCAE's work can be found in ED-130 [7], RTCA is currently updating DO294A with respect to the use of T-PEDs aboard aircrafts. Both activities are carried out under close mutual consultation. ED-130 defines the demonstration procedure, which provides recommended analyses and tests that can demonstrate that a new T-PED technology will not interfere with the aircraft equipment.

In general airworthiness certification of the GSMOB system on aircrafts covers the following essential aspects:

- Electromagnetic Compatibility (EMC) (JAR 25.1431).
- Effects on aircraft in failure conditions (JAR 25.1309) including effects of faulty cell phones.
- Operation concepts such as procedures, indications and maintenance.

Regarding the GSMOB system, Airbus was the first company to perform all necessary verification and validation activities in order to show compliance with

the applicable airworthiness requirements. The results of compliance verification activities by Airbus were reviewed by EASA under the CRI S-37 “Installation of Onboard Cellular Telephone Systems”.

Chapter 7

Conclusions

To finalize this thesis by means of conclusion, what the author considers to be the most relevant key points about GSMOB technology are highlighted next:

- Passenger use of mobile phones has been prohibited on aircraft so far because of the risk of interference with the aircraft's communication, navigation and other systems. Furthermore there is always risk of interference to terrestrial mobile networks. A handheld cellular phone left operating at aircraft cruising altitude is capable of illuminating a wide area, placing a significant load on the resources of terrestrial networks.

- To prevent mobile phones from being able to synchronize and attach to on-ground cellular networks a special unit is installed within the aircraft cabin, known as NCU (Section 3.3.3). This unit increases the noise level within the frequency bands of the cellular mobile radio systems relevant for the region the aircraft is operated in. The NCU is designed such that the relevant frequency bands are screened by increasing the noise level to lower the Signal-to-Noise Ratio (SNR) inside the cabin to make the mobile unable to decode incoming ground BTS signals. The result is that on-board mobile phones are not able to synchronize to the network and hence do not transmit.

- Based on ECC Report 93 [5], ECC approved the use of GSMOB systems in the frequency bands 1710-1785 and 1805-1880 MHz. The Decision [10], allows operation of a GSMOB system, according to the licensing conditions for the use of spectrum in the country of registration of the aircraft.

- Airbus was the first company to perform all necessary verification and validation activities in order to show compliance with the applicable airworthiness requirements. EASA approved the GSMOB system in June 2007

for a specific airplane and for identical built aircrafts. The certification basis (expressed by the EASA CRI) can be easily transferred and used for certification of such systems on other aircraft.

- Relevant EMC standards such as DO-160 apply for design of the GSMOB system, and this way it is ensured that the ac-BTS can be safely attached to the aircraft's power system.

- Passengers are used to the fact, that the use of PEDs is restricted to certain flight phases and situations. In this sense there is no difference between the GSMOB system and other PEDs which are allowed to be used in-flight already today. In case the NCU needs to be switched OFF at altitudes below 3000 m above ground level according to the ECC recommendation [5], the usual procedures as known for PEDs are taken to inform passengers that they are obliged to switch OFF their mobile phones.

- The operational approval process is still ongoing. According to the airline, the individual services could be introduced gradually (first text mode only, and voice service afterwards).

- There are issues related to 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 on the use of mobile devices in-flight. A early solution developed by Airbus in order to keep annoyance caused by passengers making phone calls below a reasonable limit is the operational mode knows as "night mode".Thus, the crew is able to deactivate all voice services and restrict the use of the GSMOB system to text-only services. Furthermore, it is conceivable that airlines arrange "non-mobiles" zones within their aircraft where passengers are not allowed to use their mobile phones. This will reduce potential annoyance in certain areas of the cabin.

  There are also security issues pending, 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.

- Nowadays it is 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, and capable of offering a service that responds to perceived customer demand. Finally, GSMOB will only be deemed a success if it meets passengers' demands and satisfies the commercial expectations of its promoters.

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