

GSM/GPRS Signal Strength Measurements in aircraft flights under 3,000 meters of altitude

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Abstract: - Nowadays an increasing demand to use mobile telephones devices in aircraft flights is being acknowledged, both in commercial and in aviation general flights. 2G and 3G mobile communications networks have a great penetration in terrestrial surface of populated areas. Nevertheless land mobile networks have not been planned to operate within the air space. The main objective of this project has been to collect GSM/GPRS signal level measurement samples in the air space used by general aviation, transmitted by terrestrial base stations. Subsequently the values of obtained signal have been analyzed in order to extract conclusions on the applicability of the current mobile terrestrial communications on board of aircraft in general aviation.

Key Words: - GSM, GPRS, measurement, base station antennas, data acquisition, aeronautics, data visualization

1 Introduction

Land GSM/GPRS networks currently offer coverage at terrestrial surface level in almost anywhere and anytime. Existing mobile phone networks were designed and optimized to provide coverage at ground level. Mobile network operators have optimized this surface coverage by means of planning two-dimensional cells to cover the whole offered service area.

Specifically used antennas have a radiation diagram with a directive gain optimized in the horizontal plane, with tilts angles very close to zero degrees and radiation diagrams where gain drops quickly when tilt angles are higher than zero degrees.

The provisions offered by network and mobile services operators do not consider the possibility of their coverage to heights above the Earth's surface or its buildings. Therefore network planning has not considered that it is just possible that these networks could provide service at the heights of flight employed by general aviation.

For this reason, the behaviour of the GSM/GPRS signal radiated at different heights has not been studied or checked to date.

However, technologies raised to give coverage to commercial aviation, such as TFTS (Terrestrial Flight Telecommunications System), have taken into account the possible existence of signals from land mobile networks, raising the coordination of interference with the terrestrial service in licensing

[1]. Indeed, companies that are beginning to offer coverage in commercial flights via satellite, such as OnAir or AeroMobile, do not allow you turn on your cell phone to less than 3.000 meters in order to avoid interacting with the terrestrial base station systems.

Therefore, the existence of the signal spreading from base stations towards the sky is known, but it has not studied the coverage that they can provide or how far they can get this coverage.

This paper focuses on precisely study the coverage offered by the public GSM network skyward making a theoretical calculation and comparing the results with the power values measured in flights that were made with this aim. To obtain this, measurement campaigns of the signal radiated by mobile telephony antennas currently installed in the direction toward the sky, up to heights of about 3000 meters, have been to be realized.

2 Overview of GSM/GPRS public land mobile networks

GSM is a second generation mobile system, with circuit-switched mode, with practically total coverage in developed areas.

GPRS represents an evolution of the GSM standard, allowing data transmission in packet mode and providing higher throughputs as compared with the circuit-switched mode. This evolution is usually presented under the designation of 2.5G to point out

that it is a transition technology between 2G and 3G. GPRS uses the same access network that GSM.

The macrocellular structure of GSM/GPRS terrestrial cellular mobile communications networks has been designed and optimized to give coverage to points of terrestrial surface.

The antennas for macrocells are mounted on ground-based masts, rooftops and other existing structures, at a height that provides a clear view over the surrounding buildings and terrain.

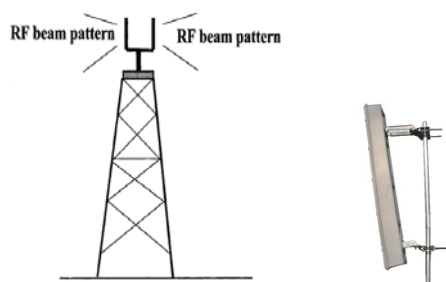


Fig. 1: Macrocell Antennas are usually mounted on towers

Normally macrocell base stations have maximum power outputs of typically a few of hundreds of watts.

In practice, all antennas have a radiation pattern envelope (RPE), which is defined as the gain geometry of an antenna relative to the isotropic ideal; i.e. an antenna that has more gain in some directions than others. RPE can be presented as a polar pattern of gain versus angle for the azimuth direction (horizontal scanning through the 360°) and the elevation aspect (scanning 360° vertically about the antenna centre point).

Sometimes an all-round (as close to isotropic as possible) or omnidirectional RPE is preferred to give good overall radio coverage in a typical mobile application (see Figure 2).

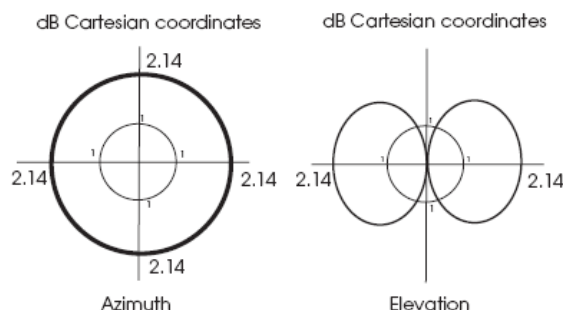


Fig. 2: Typical omnidirectional antenna pattern.

Sometimes it suits the design engineer to have a focused antenna: focusing the RF energy in a

convenient direction or rejecting RF energy coming from an unwanted angle to the antenna (see Figure 3).

Macrocell base station antennas have the form of linear antenna arrays, which are intended to obtain suitably directive characteristics in order to increase the radiation towards the serviced area (usually a sectorized area) and suppress it towards other ones.

The radiation patterns of such an antenna have a relatively narrow main beam, giving rise to the gain ranging from 10 to 20 dB, and side and back lobe levels usually between -15 and -25 dB.

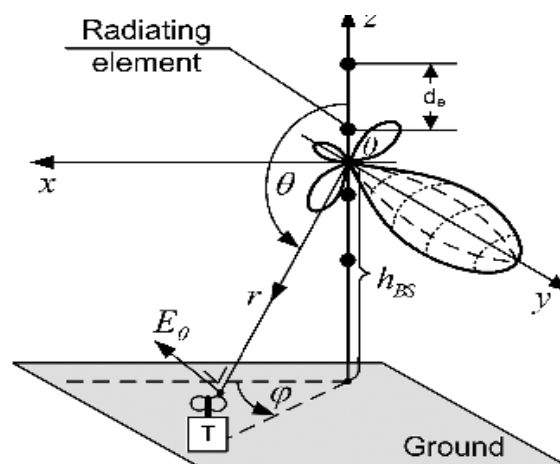


Fig. 3: Linear antenna array arrangement in the spherical coordinate system and the relative position of a mobile terminal.

Consequently, most of the energy is broadcast towards the terrestrial surface, whereas only a small portion is transmitted to the space.

In addition mechanical down-tilt is realized choosing the value so that the main lobe of the pattern is aimed towards the central part of the serviced area.

Typically down-tilts of 5° are used for rural coverage applications, increasing the previously mentioned effect.

3 Mobile Communications on board Aircraft

Mobile phone use is currently forbidden on planes because of interference with onboard communication and navigation systems.

There is an increasing interest in the potential for passengers to use their mobile phones on aircraft.

With the recent development of "pico-cell" devices, the use of GSM on board aircraft was being planned by some airlines. It was considered, however, that there was insufficient evidence to ensure the aviation safety issues had been addressed.

Plans have been developed across EU countries to introduce in commercial aviation the technology which permits mobile calls without risk of interference with aircraft systems. Individual airlines would need to decide if they wanted to introduce the technology.

The proposed system utilizes an on-board base station in the plane which communicates with passengers' own handsets. The base station, called a pico cell, is low power and creates a network area big enough to encompass the cabin of the plane.

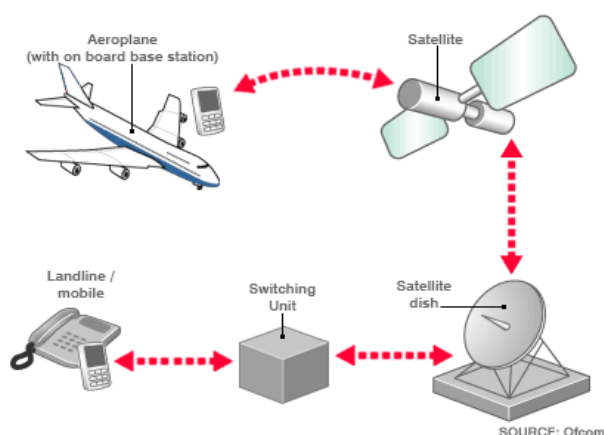


Fig. 4: Scheme of planned GSM on board aircraft

The base station routes phone traffic to a satellite, which is in turn connected to mobile networks on the ground. Mobile handsets will then be able to use the aircraft's network service to make and receive calls which will be routed via a satellite link to the network on the ground.

A network control unit on the plane is used to ensure that mobiles in the plane do not connect to any base stations on the ground. It blocks the signal from the ground so that phones cannot connect and remain in an idle state.

The service would allow calls to be made when a plane is more than 3,000 meters high. Once the aircraft reaches a minimum height of 3,000 meters, the system may be switched on by the cabin crew. Mobile phone handsets and on-board base station must be switched off during take-off and landing to ensure they do not interfere with mobile networks on the ground.

Calls will be billed through passengers' normal service providers.

The current plan is for 2G phones only but if services proved successful, it could be rolled out to 3G and other standards in the future.

4 Data Acquisition

Data that have been collected are values of emitted power by GSM/GPRS public network antennas at heights of general aviation, that is, between 1000 and 3000 meters. Clearly, the data acquisition system has been designed to suit to the specific limitations that appear when the measures have to be acquired at various altitudes and in different external conditions.

4.1 Data acquisition system

In order to collect data flights in hot-air balloon and in light aircraft have been made.

The balloon provides continuity in altitude that flights in light aircraft do not offer and a lower velocity.

The light aircraft flight has the advantage of the facility to fly through the preselected area and it can maintain constant the altitude of the flight during the sample acquisition. We lose the continuity in altitude but many samples on the same level of altitude are obtained.

The data collection system must be portable and not too bulky in order to be placed in the balloon and the plane safely. In addition, it must have enough electric power autonomy to take measures throughout the whole flight time (in the case of the light aircraft, flight autonomy is close to about three or four hours). A specific system for capturing, measuring and processing of radio signals has been developed for this application.

In Figure 5, we present the diagram of measurement automatic system used to evaluate GSM/GPRS signal at a particular location in the air space.

The frequencies in which the system must collect and store received power data are located in the 900 and 1800 MHz bands, the frequency of the GSM channels [2].

GSM-900 uses 890–915 MHz to send information from the Mobile Station to the Base Transceiver Station (uplink) and 935–960 MHz for the other direction (downlink), providing 124 RF channels spaced at 200 kHz. Duplex spacing of 45 MHz is used.

GSM-1800 uses 1710–1785 MHz to send information from the Mobile Station to the Base Transceiver Station (uplink) and 1805–1880 MHz for the other direction (downlink), providing 299 channels. Duplex spacing is 95 MHz.

The study has focused on monitoring, storage and subsequent processing of the power level received from the carriers of the downward channel, between the GSM/GPRS terrestrial base station and the mobile phone on board.

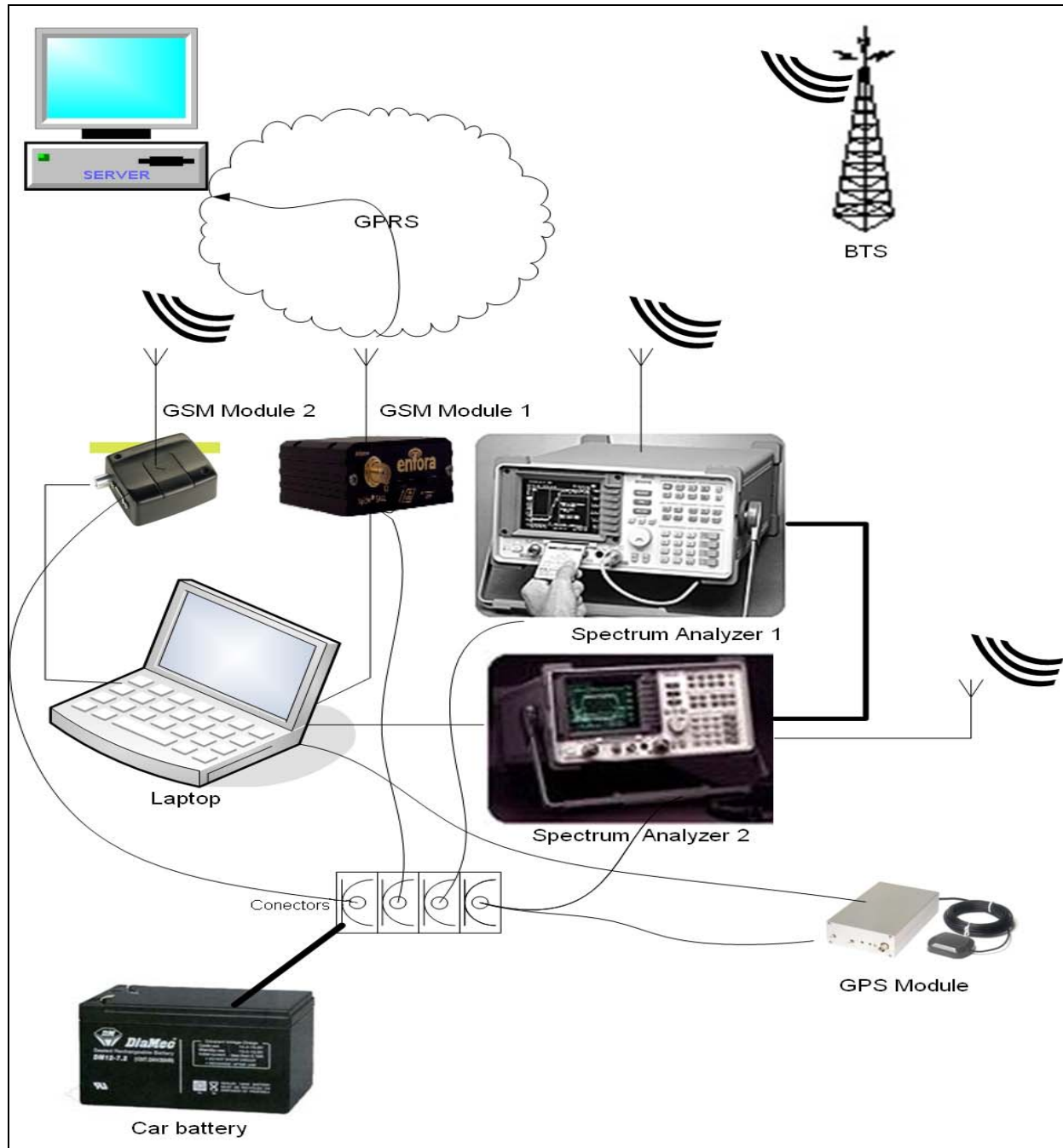


Fig. 5: Measure acquisition system

With this aim we have used two spectrum analysers (one for the 900 MHz band and other for the 1800 MHz band) [3].

The spectrum analysers run on two batteries connected to an inverter that converts direct current to alternating current. This gives the system autonomy of about three or four hours.

Two GSM/GPRS modules are also added to the system. The simultaneous use of the GSM/GPRS modules allows the possibility of measuring the power in a continuous way and simultaneously sends

data to the server without interfering with the power measures. The first module is used to measure directly the received channel power. The second module is used to establish a GPRS session and send data via TCP connection to a server on land that will keep the sent data. The modules can operate in data mode or command mode. To establish the TCP connection, the entire process is done command mode.

To receive the signal from GSM/GPRS base stations we used a $\lambda/4$ monopole antenna, showed in Figure 6.

The above mentioned antenna has been characterized and calibrated in our laboratory. Previously the antenna factor with the used cables has been calculated.



Fig. 6: Used $\lambda/4$ monopole receive antenna

Therefore the signal strength values in any point of the coverage area are converted and presented in dBm.

Signal strength (P) in dBm is defined as:

$P \text{ (dBm)} = 10 \log (P_{in} / 0.001)$, where P_{in} is in W.

It is necessary to know for each sample, the time and place where it was collected. For this reason, we use a GPS system with the measuring instruments so we can know the instant position [4]. It has used a GPS module that performs calculations at 4 Hz, that is, four position calculations per second.

To store all data related to power measures, position and time a laptop computer has been used. A GPIB bus allows connecting and controlling the spectrum analyzers. The GSM modules communicate with the laptop through the RS-232 port using AT commands. The GPS module also connects through the RS-232 port exchanging messages of the NMEA specification. We have used RS-232 to USB converters, USB hub and USB inputs on the laptop.

For monitoring, capture and storage of data collected by the spectrum analysers, an application based on the software designed to collect data from measuring devices, LabView, has been developed. We can say significantly that the processing speed is important because data collection is done in flight, at a cruising speed of around 150 km/h, travelling 42 meters per second.

A program in C # has also developed. This program is responsible for initializing the GSM modules through the AT commands. Once initialized, is responsible for collecting power measures that

provide as well as the values of altitude and position provided by GPS module.

The spectrum analysers run on two batteries connected to an inverter that converts direct current to alternating current. This gives the system autonomy of about three or four hours.

4.2 Format and processing of collected data

Once we made the measuring sessions and measures and with available data collected during the flight of the light aircraft and hot-air balloon, it is necessary to make an initial processing of this information to adapt formats and data types.

For each flight two different types of files are created:

-- A text file generated by the C# program with mark time, the power data received from the GSM modem and the GPS data.

-- Two DAT file extension with the time marks and the samples of the spectrum analyzers. One file contains the data from the analyzer centred on the 900 MHz band and other one data focused on 1800 MHz.

A set of programs in C# language have been created in the research group for preparing data so that they can be more easily represented.

The formats of data for each type of file can be seen in Fig.7.

Time stamp	
Sample ID = 1	Sample value
Sample ID = 2	Sample value
...	...
Sample ID = N	Sample value

Format of received data by LabView program

Time stamp	Altitude	Longitude	Latitude	Coverage	Power
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Format of received data by C# program

Time stamp	Altitude	Longitude	Latitude	Coverage	Power
Sample ID = 1	Sample value	Sample ID = N	Sample value

Final format of received data

Fig. 7: Format of collected data

5 Measurements campaign

The campaign of received signal strength measurement has been realized in La Rioja in the north of Spain (see Figure 8).

The chosen zone is placed in the air route from Bilbao to Madrid and can be an example of a standard route of general aviation.

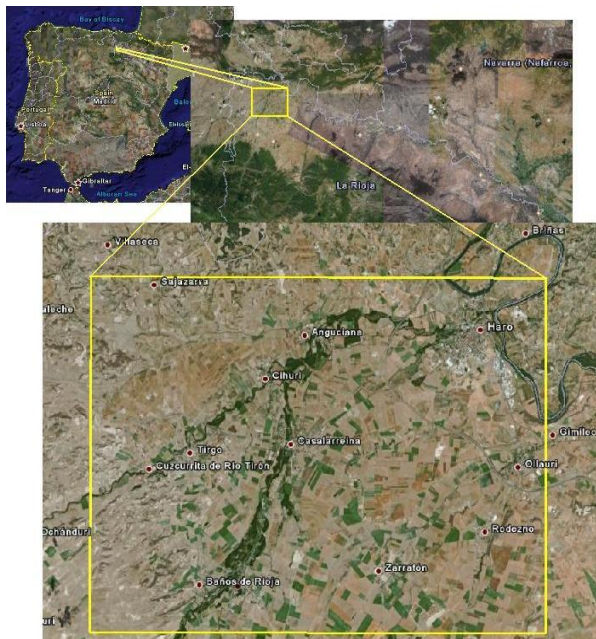


Fig. 8: Location of measurements area

In Figure 9 the hot air balloon used in the measurements flight is showed.



Fig. 9: Used hot air balloon

The antennas were connected in the low external part of the basket.

In Fig.10, the system prepared and assembled on the basket of the balloon can be appreciated; one of the flights was made with this system.

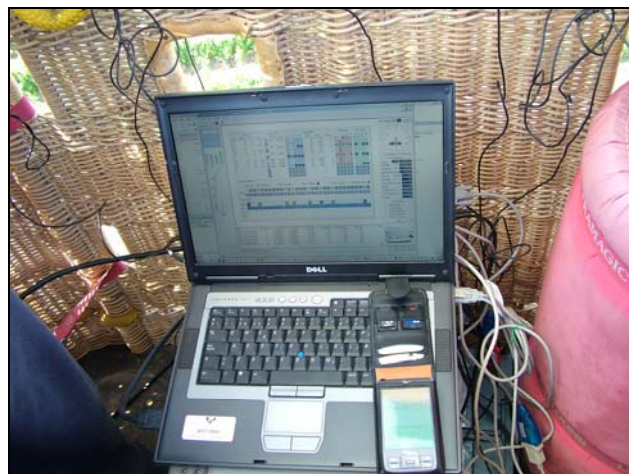


Fig. 10: Assembled system on the balloon

In Figure 11, path and heights of flight route are represented.

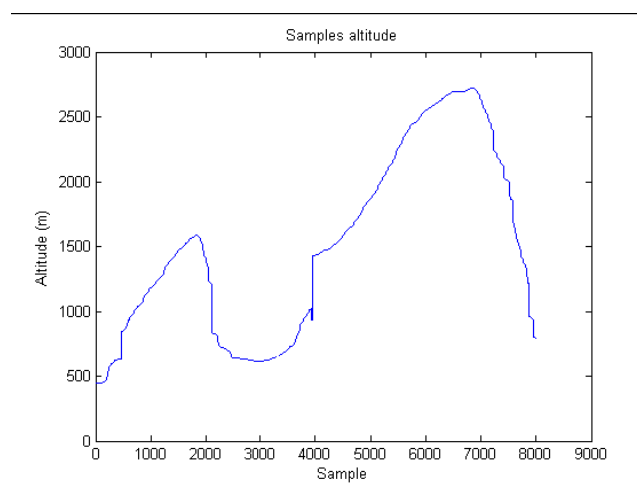


Fig. 11: Path of route and altitude of each measurement sample point

As we can see in Figure 11, a whole of 8000 samples were taken in the flight, changing the altitude between 500 and 3000 meters.

For each of 8000 samples we have registered:

- Measures of the GSM-900 downlink spectrum.
- Measures of the GSM-1800 downlink spectrum.
- Measures of signal strength in a GPRS active channel.

Additionally, a measurement campaign using a light aircraft of general aviation has been carried out.



Fig. 12: Aircraft used for measurements

The measurement system equipments were placed inside the aircraft, suitably held in order that measures were stable during the flight.



Fig. 13: Disposition of the spectrum analysers inside the aircraft

The antennas were placed in the low part of the fuselage of aircraft, in order to maximize the received radiation from the land base stations.



Fig. 14: Disposition of the antennas outside the aircraft

In Figure 15 tracing of the followed air route in samples acquisition is represented.

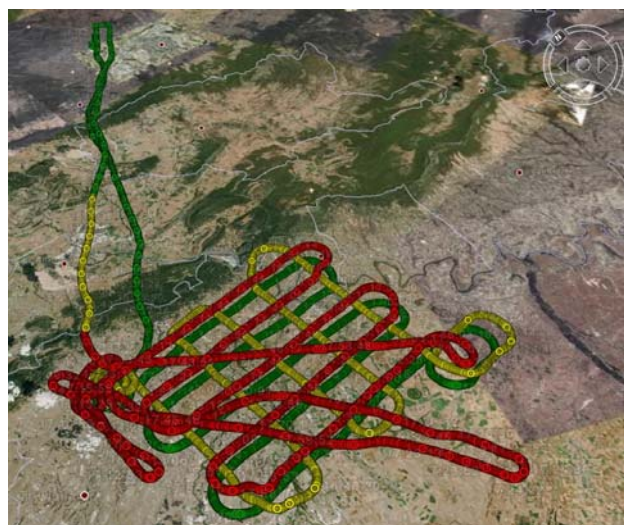


Fig. 15: Tracing of the flight route

In this image we can see the takeoff, landing and route of going and return to the area of study.

Flights in the measurement zone are divided in three heights depending on the color. The green points refer to routes from the light aircraft to 1100-1200 m. of altitude, the yellow ones to 1700-1800 m. and the red one to 2700-2800 m.

The over flown land area contains several state and provincial roads. Therefore there exist some base stations of mobile telephony along it, since we show in Figure 16.



Fig. 16: Location of the land base stations in the zone of flights

The flight took two hours and a half.

1800 samples of each one of the three levels of altitude were registered.

In the same way as in hot air balloon case, in every sample the following information was stored:

- Measures of the GSM-900 downlink spectrum.
- Measures of the GSM-1800 downlink spectrum.
- Measures of signal strength in a GPRS active channel.

6 Results

6.1 Theoretical simulation

Based on the radio propagation theory, we have developed a program that can predict the power received at any point in space, emitted by the terrestrial base station antenna of the GSM/GPRS service.

The theoretical model estimates the existing power at coordinates (x, y, z) where data from the flights have been collected.

In this model the effect of basic losses in excess over these of free space, especially radio signals attenuation by metal fuselage of the light aircraft, has been considered.

With this aim we use data of existing antennas in the area where flights have been conducted, their position, power and frequency of emission, radiation diagrams of these antennas, as well as their orientation and elevation angle.

As an example, a graphical representation of the estimated power in a plane at 1700 meters is shown in Figure 17. It is the result of the simulation for one of the antennas, emitting at a frequency of 956.4

MHz, with an orientation of 20° and an elevation of 0° . The radiation diagram belonging to this antenna is shown in Figure 18.

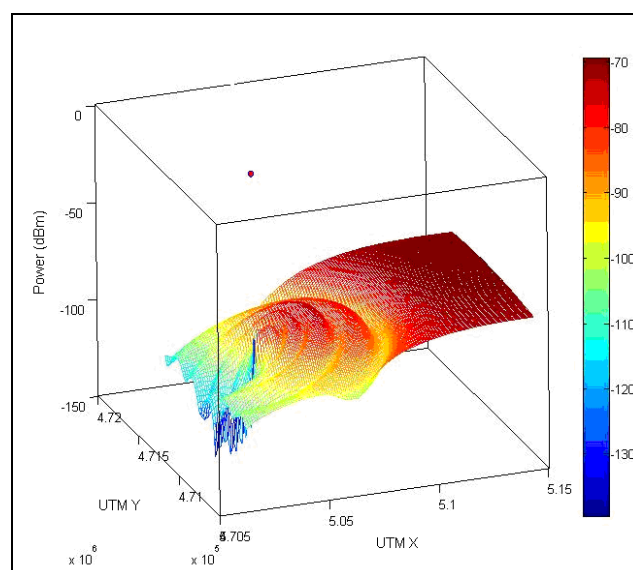


Fig. 17: Estimated power at 1700 m

The height and colour of the figure at each point representing the power level in dBm's that there is for that pair of coordinates UTM X and UTM Y.

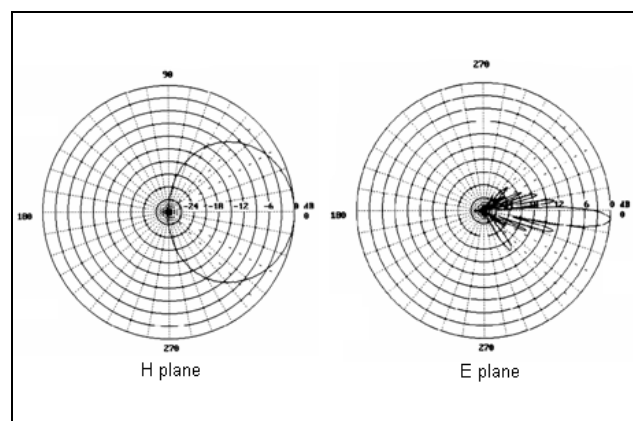


Fig. 18: Radiation diagram of the antenna

6.2 Signal strength values

Below an example of the results obtained by means of data capture on hot-air balloon is shown. The characteristics of the followed route, in the air direction Bilbao-Madrid, can be seen in Figures 19 and 20.

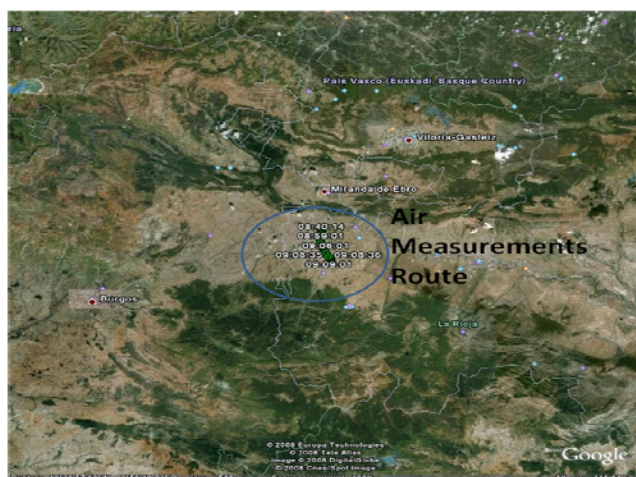


Fig. 19: Route followed by the balloon

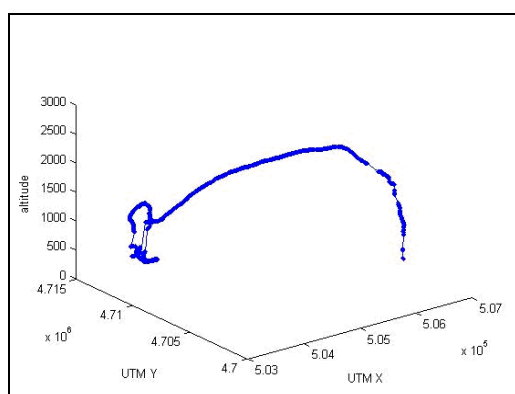


Fig. 20: Coordinates for the route followed by the balloon

In Figure 21 we show the power measures taken in the air route (in dBm's) for a carrier in which a channel of GPRS permanent connection land-hot-air balloon has established. In the abscissa axis the number of sample is shown, so that samples are represented sequentially ordered according they were collected during the flight.

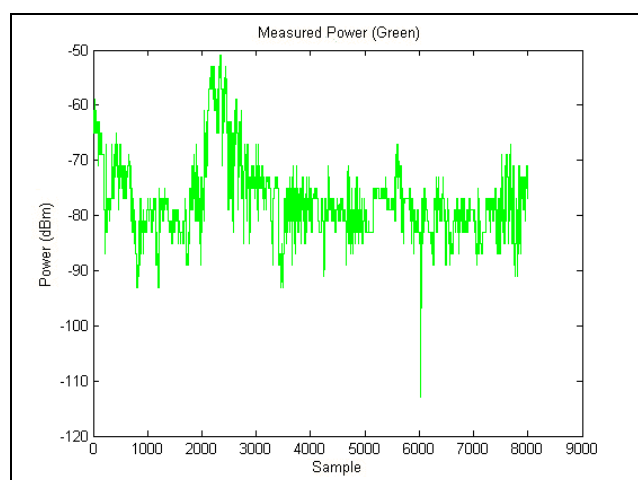


Fig. 21: Measured Signal strength for one active channel of GPRS

The channel remained permanently active during the flight, with a received signal strength superior to the receiver sensitivity, better than -104 dBm for GSM 900 band, except a few instants to an altitude of 2600 meters. This means that the communication in these moments returned to connect in a few seconds after handoff were realized.

In Figure 22, in the same graphic, measured and calculated by the simulation model developed to estimate the received power, are shown.

The result corresponds with the simulation for a single source, the one of highest level of signal received at the mobile receiver.

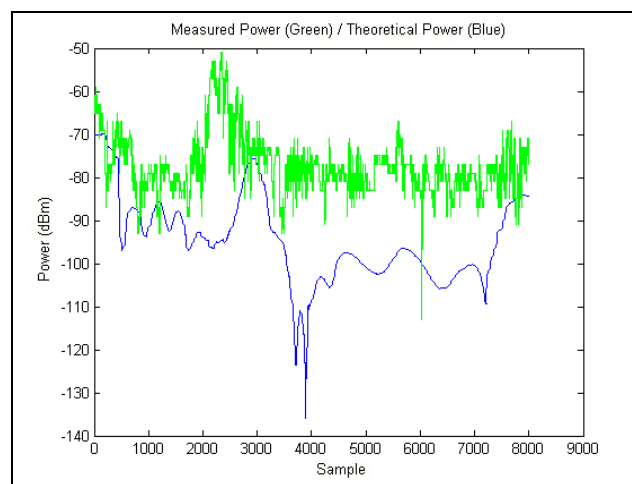


Fig. 22: Measured power and estimated power

Notice the measured power is like the simulation one, especially in the first samples. There is a small gap between the two lines that can be explained by slight differences between the actual orientation of the antenna and introduced orientation into the theoretical model.

7 Conclusions

This research demonstrates that reasonably reliable mobile-network connections could be established for aircraft flying below about 3000 meters.

It has been proven that the signal of terrestrial mobile service radiated into the sky between 1000 and 3000 meters of altitude has a received power level higher to the specified sensitivity in conventional receivers in most of a selected trajectory within the air route Bilbao - Madrid. The power of this signal varies depending on the proximity to the antenna that emits it.

In addition, we have also proven that the quality of the received signal in terms of bit error rate, BER,

is above the minimum value specified for the GPRS connection in practically all of the selected route.

We have also implemented successfully handover functions during connections.

It has checked that generally measured values are higher than estimated values.

These discrepancies can be caused by interferences, that is, co-channel or adjacent channel interference components are involved in the measured signal reception. These components are caused by multiple sources that have not been taken into account in the theoretical model.

Moreover, under the actual air conditions of radio propagation, the effect of basic losses in excess over these of free space may be lower than those considered in our used simulation software. Therefore we consider that it is necessary to continue with a more detailed study on interferences.

Finally, an adequate level of radio coverage for applications in general aviation routes can be achieved by making changes in the tilts of the antennas currently used in the GSM/GPRS network in order to broadcast with elevation angles above zero degrees and properly planning locations and orientations of base stations to generate three-dimensional cellular structures.

8 Acknowledgments

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