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FACULTY OF ELECTRICAL AND ELECTRONICS ENGINEERING

Bachelor's Degree Final Project

DESIGN OF A DRONE BASED MEASUREMENT SYSTEM FOR GSM SIGNALS

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Title of the project: Design of a Drone Based Measurement System for GSM signals.
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This bachelor's degree final project called "Design of a Drone Based Measurement System for GSM signals", was conducted by Alvaro Zornoza Uña, student of Bachelor Degree in Industrial Electronics and Automation at Technical University of Madrid (Spain), during an Erasmus + exchange at Kaunas University of Technology (Lithuania) during the spring semester of 2017.

On 19th June 2017 the present document was presented to the supervisor of the project, D. Mindaugas Žilys who has overseen the project during its whole development, ensured that the student achieved the established objectives and requirements at beginning and decided to give a mark of:

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Abstract

Nowadays, there is a growing interest to use drones professionally in telecommunications and industrial environments. Drones are a rapidly evolving technology with potential for different surveying and measurement purposes. Drones are able to perform surveying tasks while flying in the air quickly and inexpensively. The recent developments on the field of technology and the potential applications of drones result in an increasingly widespread use.

The objective of this thesis was to research if a drone based measurement system radio frequency signal exposure assessment it is a feasible concept. The present project includes the search of the necessary components (embedded-systems computer and electronic components), the design and implementation of the electronic circuit, the programming of the software needed for the experiments, the performance of experiments with the developed system and the analysis of the data obtained.

The research showed that a drone based measurement system for radio frequency is fit for this purpose. The system can produce accurate and timely results, being capable of replacing more traditional measurement methods that requires large amounts of time, effort and money.

Keywords: unmanned aerial vehicle, unmanned aerial system, UAV, UAS, drone, drone based measurement system, embedded system, measurement system, radio frequency exposure assessment, RSSI, radio signal strength indicator.

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Chapter 1

Introduction

Unmanned aerial vehicles (UAV), also known as drones, are flying machines without an on-board human pilot or passenger. They usually have sensors attached, such as digital cameras. Drones can be either under remote control by a human operator or working fully or partially autonomously.

Although drones have military origins, they have lately been used more and more for civilian purposes. The great technological development, the cost of electronic components and economies of scale have made possible for anyone to have a drone for entertainment purposes today [1].

Nowadays, there is a growing interest to use drones professionally in telecommunications and industrial environments [7]. Drones are able to perform surveying tasks while flying in the air quickly and inexpensively. The recent developments on the field of technology and the potential applications of drones result in an increasingly widespread use.

Wireless signals and networks are everywhere in today's world. Even though they are more reliable than ever before, wireless networks still struggle with weak coverage, blind spots, and interferences [17]. An appropriate understanding of wireless signal propagation is essential for increasing coverage, optimizing performance and minimizing interference for wireless networks. There are some methods for collecting wireless measurements that involve human operators and manual collection of measurements, that requires large amounts of time, effort and money [26].

1.1 Motivation

This project arises as a result of an increasing interest on the research of uses of drones for measurements. The objective of this bachelor's degree final project is to figure out if a drone based measurement system for radio frequency is fit for this purpose. In the following pages, a method to assess Received Signal Strength Indication of cellular phone antennas in a real environment is presented.

Ground measurements offer useful indications about the transmitted signal. However, they have some critical limitations, like reflections from the ground, buildings and vegetation.

Wrong designed antennas or even faulty ones (e.g. because of a wrong installation) could cause serious perturbations with all the implications that this has for telecommunication companies.

The only way to perform RF measurements is ”on air”. Using helicopters could be a solution, but it is expensive and it does not have a good accuracy. The development of systems with drones offers new possibilities to make highly accurate airborne measurements.

Although radio-frequency measurements were selected, any other kind of sensor could be chosen. The system developed has some flexibility, modularity and adaptability on the matter of changing the sensor for a different purpose.

1.2 Objetives

The first part of the project focuses on finding the components that are capable of working together as one system. The second one consists on making them work with each other and produce results that are useful for my research.

The second part includes three elements:

1. Design and implement the GSM signals measurement system.
2. Programming the software needed for the operation of the project.
3. Perform experiments and analyse the data obtained.

1.3 Structure of the document

To facilitate the reading of the document, the contents of each chapter are detailed:

- In chapter 2, an overview of the technologies used in this project is presented.
- In chapter 3, current trends on these sorts of technology are reviewed.
- In chapter 4, the proposed solution for both the hardware and software systems is explained.
- In chapter 5, the existing regulations on drones on European Union (EU) and national levels are reviewed and also the drone safety and operational flight procedures used during the experiments.

- In chapter 6, the results from the experiments on the field are discussed.
- Finally, the conclusions are used to summarize the project and explore future lines of work in this area.

Chapter 2

Background information

2.1 Unmanned Aerial Vehicle (UAV)

2.1.1 Definitions and terminology

The large number of terms being used interchangeably to describe unmanned aircraft can often lead to confusion. The different terms often come from the different requirements and concepts between military and civilian systems or have regulatory or legal importance.

These terms and acronyms for this technology include: drone, UAV (Unmanned Aerial Vehicle), UA (Unmanned Aircraft), UAS, (Unmanned Aerial System), RPA (Remotely Piloted Aircraft) and RPV (Remotely Piloted Vehicle). As laws are still being written and this technology becomes more widespread, there is a clear need for a single prevailing term that is both comprehensive and well received [1].

The most common term used in the media today to describe an unmanned aircraft is drone. This term will be used during this project. However, the term drone often concerns a level of stigma inherited from their controversial military applications; e.g. United States Army uses it against terrorist organizations.

A more preferable and descriptive term could be Unmanned Aerial Vehicle, which refers to a pilotless aircraft, a flying machine without an on-board human pilot or passengers. However, the use of the word 'unmanned' leads to confusion about the actual autonomy of these machines [2]. While all drones have sensors, they also have ground operators, who can take the control of the vehicle if it is flying defectively.

A few years ago, the U.S. Department of Defense (DoD), followed by the FAA and the European Aviation Safety Agency (EASA), adopted the term UAS or Unmanned Aircraft System. This was meant to signify that UAS are aircraft and as such airworthiness will need to be demonstrated, and they are also systems consisting of ground control stations, communication links, and launch and retrieval systems in addition to the aircraft itself.

In practice, UAS and UAV are often used interchangeably, and only when the system aspect is important (mainly for legal/regulatory reasons) does UAS have the preference.

Other names included Remotely Piloted Vehicles (RPVs), a term that was used in the Vietnam War. Today the United States Air Force (USAF) has mainly substituted RPV for Remotely Piloted Aircraft or RPA, a term used to include both the aircraft and the pilot, while the United Kingdom has designated them as Remotely Piloted Air System (RPAS).

2.1.2 Fixed-wing aircraft vs rotatory-wing aircraft

One of the first decisions that anyone looking to employ UAV technology needs to consider is whether to choose a "Fixed Wing" or a "Rotary Wing" aircraft. Both categories possess a set of advantages and limitations which must be taken into account in order to decide which is the most suitable for the specified application.

Rotatory-wing and fixed-wing aircraft share the same flight dynamics principle. It is necessary to create an air flow over the wings/propellers to generate an upward force called lift, that overcomes the aircraft's weight and holds it in the sky. Therefore, the difference between both types is how to generate this lift.

Engines of fixed-wing aircraft are designed to move it forward at high speed. The air flow rapidly over the wings, and therefore a pressure difference is generated. Wings make lift by changing the direction and pressure of the air that crashes into them. These aircraft are not able to hover over a specific area since they are always moving in a horizontal direction. Furthermore, they are dependent upon either a launcher or a runway to facilitate take-off and landing. However, fixed-wing aircraft also have some advantages: They are characterised by a simpler structure, more efficient aerodynamics and less energy consumption. All these features provide the benefit of longer flights duration at higher speed [5].

Figure 2.1: Quadcopter vs Rotatory wing Aircraft

On the other hand, a rotary-wing aircraft (also known as multirotor aircraft or rotorcraft) uses lift generated by wings, called rotary wings or rotor blades that revolve around a mast. The International Civil Aviation Organization (ICAO) defines rotorcraft as "aircraft supported in flight chiefly by the reactions of the air on one or more power driven rotors on substantially vertical axes". Rotorcrafts involve a greater mechanical complexity which translate generally into lower speeds and shorter flight ranges. Therefore, their advantages are their ability for vertical take-off and landing and their capacity to hover and perform agile manoeuvring. In addition, they are far easier to precisely control compared to fixed-wing aircraft.

Multirotor aircraft are divided into classes of vehicles based on the number of rotors the aircraft uses and they frequently use brushless DC motor to rotate the rotors and generate lift. For the purpose of this project, quadcopter is the main element, which is a multirotor helicopter with four rotors.

2.1.3 Flight dynamics

Any aircraft in flight is able to rotate around three axis that are perpendicular to each other, whose intersection point is located on the centre of gravity; they are transverse (or lateral), the longitudinal and vertical axis.

Talking about fixed-wing aircraft, these rotations are produced by torques (or moments) around the principal axis. On an aircraft, those are intentionally produced by moving control surfaces, which vary the distribution of the net aerodynamic force on the vehicle's centre of mass. Elevators (moving flaps on the horizontal tail) produce the pitch, rudder on the vertical tail produces the yaw, and ailerons (flaps on the wings that move in opposing directions) produce the roll [2].

We also have the quadcopter. Quadcopters generally use two pairs of identical fixed pitched propellers; two clockwise (CW) and two counter-clockwise (CCW). Basically, the multirotor movements are produced by changing the rotational speed of the motors properly.

To make the multirotor rotate about the roll or pitch axes, the flight controller makes the motors on one side of the multirotor spin faster than the motors on the other side. This means that one side of the multirotor will have more to lift than the other side, causing the multirotor to tilt.

The reason behind using two different pairs is avoiding the tendency of the drone to rotate around the yaw axis [9]. This is due to Newton's third law of motion, "for every action, there is an equal and opposite reaction." The body of the multirotor will tend to spin in the direction opposite the rotational direction of the propellers. Using pairs of rotors spinning in opposite directions, it is possible to cancel out this effect and make it so the multirotor does not spin around the yaw axis.

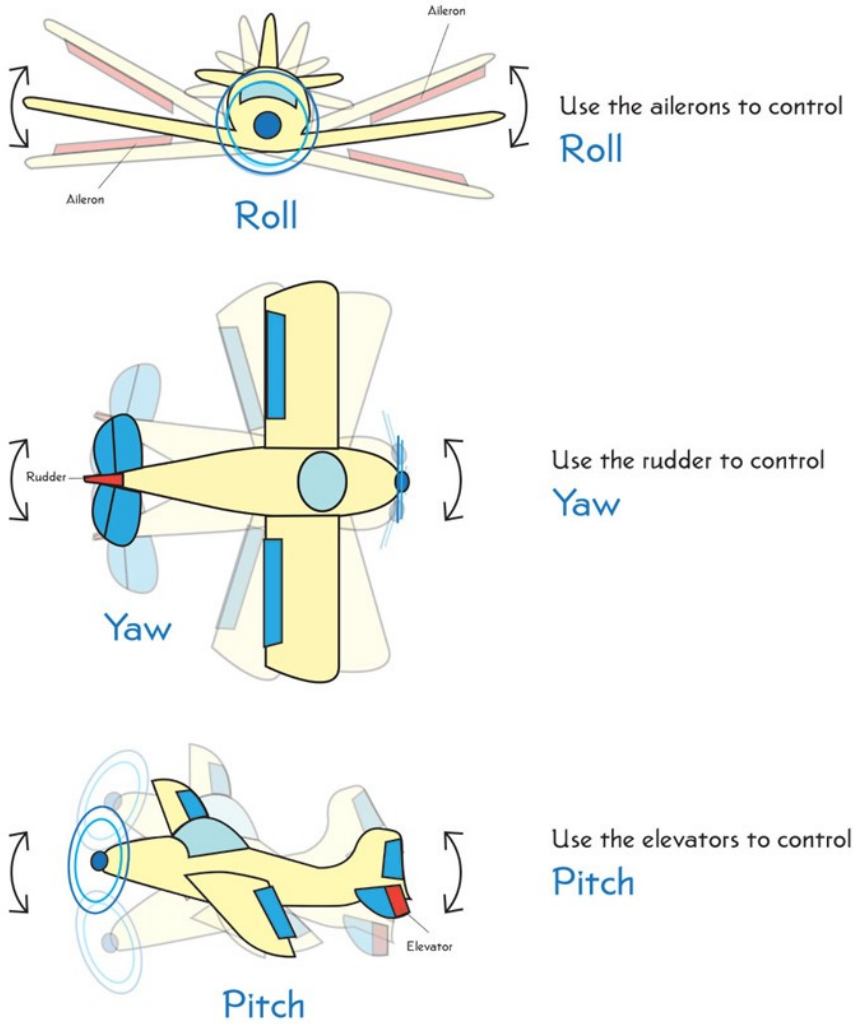


Figure 2.2: Roll, pitch and yaw angles in Fixed-Wing Aircraft

To rotate the multirotor around the yaw axis, the flight controller will slow down opposite pairs of motors relative to the other pair. This means the angular momentum of the two pairs of props will no longer be in balance and the aircraft rotates.

Finally, the control of altitude is usually called throttle control. The lift produced by the drone is equal to the amount produced by each of the engines. Therefore, if the force of gravity equals the force of the lift produced by the motors, the multirotor will maintain a constant altitude. If the lift produced by the multirotor is greater than the force of gravity, the aircraft will gain altitude. Finally, if the lift produced by the multirotor is less than the force of gravity acting on the multirotor, the multirotor will fall.

In figure 2.3 you can see the different movement of the quadcopter depending the speed of the motors.

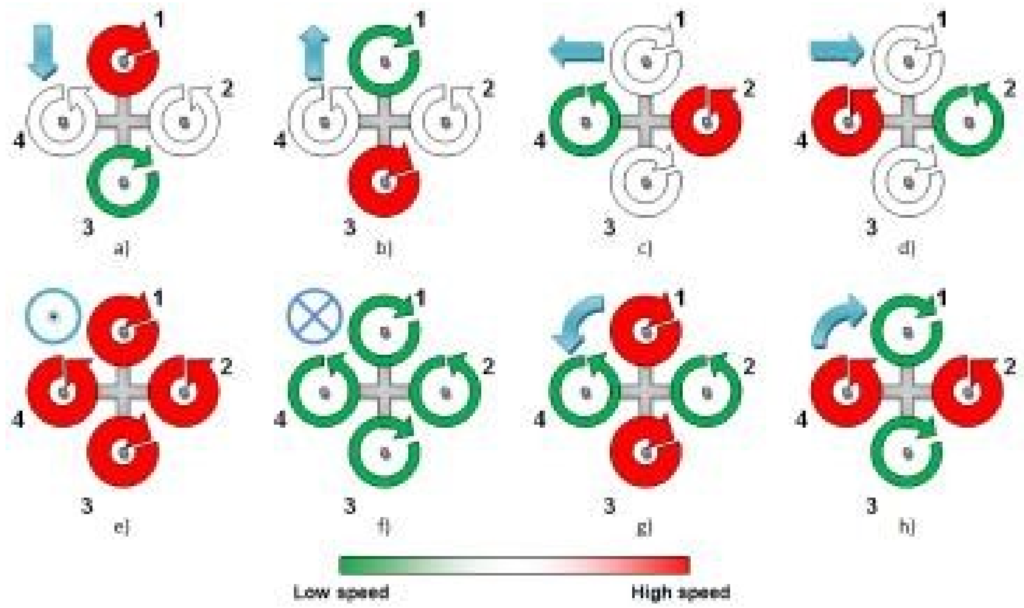


Figure 2.3: Motor control on movement of a quadcopter

2.1.4 Quadcopter elements

In order to build a quadcopter successfully, most important step is to know what parts you need and to understand their functions.

A) Frame

The frame is the structure of a quadcopter and all the other parts are mounted on it. Frames come in a large variety of layouts, sizes, and materials. Some materials used in quadcopter frames include plastic, glass fibre, aluminium tubing, carbon fibre tubing or carbon fibre plate.

(a) Carbon fibre racing drone frame

(b) Brushless motor

B) Brushless motor

A brushless motor is an electric motor that does not use brushes to make the change of polarity in the rotor. Electric motors have traditionally had a collector commutator bars or a pair of slip rings. These systems, called brushed motors, produce friction, diminish performance, give off heat and noise and require much maintenance.

They are powered with alternating current (hence 3 each motor wires) and to do this an ESC or frequency inverter is required to transform DC power to AC power at a certain frequency to give the proper speed at each time according to the decision of the flight controller.

A brushless motor consists of two main sections. The rotor is the part that rotates and has the magnets mounted in a radial pattern. The stator is the part that does not rotate, and has elements called electromagnets or coils.

C) Electronic Speed Controller (ESC)

An ESC is a component that varies (and slows down) the rotational speed, or changes to the direction of the shaft of an electric motor. Brushless ESC systems create a tri-phase AC power output of limited voltage from an onboard DC battery and the Flight Controller signal, to run brushless motors by sending a sequence of AC signals.

Figure 2.5: Electronic speed control (ESC) specified for a current of 20A

D) Flight Controller

Usually, talking about controlling a plane, the pilot has precise control over the motor. A nudge of the throttle translates to a proportional increase in RPM. The same is true of input to the rudders, ailerons, flaps, and other parts involved in changing speed or direction.

The difference with multi-rotors, is that no human is capable of controlling the rotational speeds of four or more motors simultaneously with enough precision to balance a craft in the air. This is where flight controllers come into play.

The flight controller is the nerve centre of a drone, a programmable computational brain. Generally, it is a printed circuit board with an Intel or ARM processing chip as the CPU. It takes the information from the onboard sensors (e.g. GPS, gyroscopes, barometer), and responds to the pilot's requests sending signals to the ESCs which determine how to manipulate the motors accordingly.

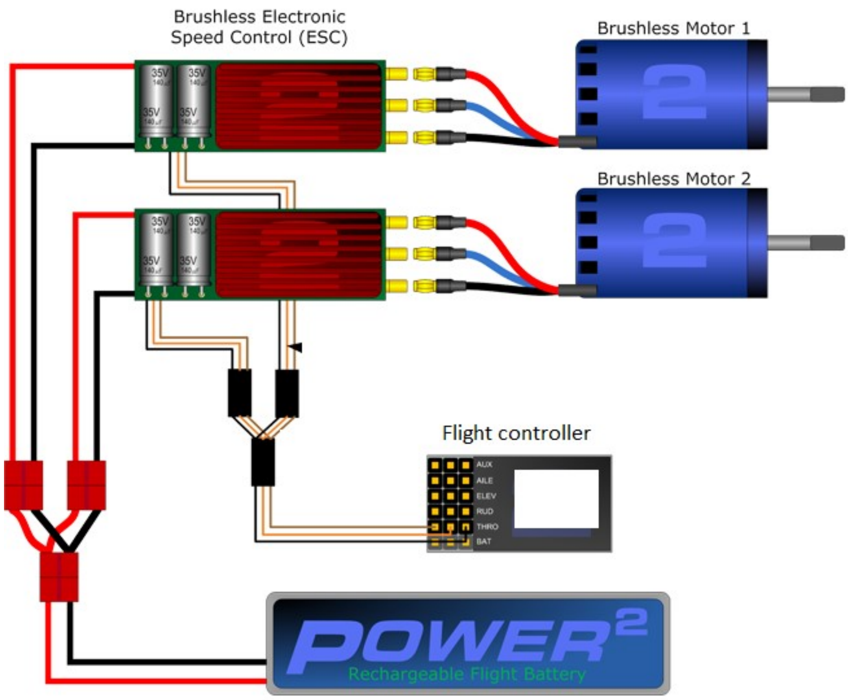


Figure 2.6: Multi-Engine ESC wiring diagram

E) Propellers

The propellers convert rotatory motion from a brushless motor to provide propulsive force. It is possible to find propellers of different sizes and materials, such as nylon, carbon fibre or ABS. Some propellers are built to improve speed while others are geared toward stability and durability.

F) Sensors

A sensor is a device that detects changes in electrical, physical or other types of magnitudes and produces an output. Sensors allow drones to collect data about its state or to detect changes in their surroundings that allow them to manoeuvre better and also collect critical data about the object they are inspecting. There are different types of sensors that can be used in a drone. Several examples are presented here:

a) Global Positioning System (GPS)

The global positioning system is a satellite navigation system that uses a radio receiver to collect signals from orbiting satellites to determine position, speed, and time. This navigation system is more accurate than other forms of navigation, and provides position knowledge within a few meters.

Advanced drones make use of GPS receivers within the navigation and control loop which allows for some smart features:

-Position Hold: Allows the drone to maintain position at a fixed altitude and location.
-Return to Home: The drone remembers the location from where it took off.
-Autonomous Flight: The flight path of the drone can be predetermined by establishing GPS waypoints that define the trajectory.

b) Inertial Measurement Unit (IMU)

The IMU is the most crucial sensor for determining the state of the drone and maintaining direction and flight paths. It is composed of a combination of accelerometers and gyroscopes for the purpose of determine the drone's velocity, orientation and gravitational pull. Interpreting its output allows us to represent the craft in 3D space with six degrees of freedom: 3D position of the centre of mass and the three flight dynamic angles (yaw, pitch, roll).

c) Current Sensors

Current sensors can be used to monitor and optimize power drain, safe charging of internal batteries, and detect faulty conditions with motors or other areas of the system.

d) Magnetic Sensors

These sensors can be used to sense the presence of magnetic objects and fields and can be helpful in determining the position of the drone

e) Infrared and Thermal sensor

The potential uses for infrared sensors, especially in cameras, are vast and include search and rescue, surveillance, crop and forest health, pipeline inspection, leak detection, etc. It is especially useful in night-time or cloudy conditions.

A thermal camera can hence detect areas of high temperatures. It can reveal overheating sections of electrical equipment in various devices such as switchgears and substations. They can also be used for night vision and surveillance.

f) <u>Camera</u>

A camera includes an image sensor which can detect and transmit information about what constitutes an image. It is done by converting the variable attenuation of light waves into signals. A camera can be attached to a drone in order to create a digital image of the pictures taken by the drone. They can be used in different industries, such as agriculture, construction, mining, etc.

The camera DJI Zenmuse X3 (figure 2.7) is used in the present project.

Figure 2.7: DJI Zenmuse X3 camera

2.2 Single-board Computer (SBC)

A single-board computer (SBC) or embedded computer is a complete computer built on a single circuit board, with microprocessor(s), memory, input/output (I/O) and other features required of a functional computer.

In the area of drones, they have started a new era of smarter, faster and more powerful aerial platforms. These computers are platforms for developers to build on, which can turn drones into truly intelligent flying robots that can perform complex computing tasks and advanced image processing.

They are optimized for energy efficiency. Different ports, such as USB, Ethernet, Mini-PCIe, HDMI, UART, SPI and I2C, are usually included. These interfaces allow for all manner of sensors and add-ons to be connected.

Figure 2.8: Raspberry Pi 3 Model B

Raspberry Pi (figure 2.8), developed by Raspberry Pi Foundation, is the most famous in this kind of computers. By November 2016 they had sold eleven million units for a price of only thirty-five euro each [20]. Since the success of Raspberry Pi, SBCs proliferated and became more popular, accessible and affordable.

2.3 Flight Regulation

Drones offer huge potential for developing innovative civil applications in different sectors. The development of drones has opened a promising new chapter in the history of aerospace. Within 20 years, the European drone sector is expected to employ directly more than 100,000 people, and to have an economic impact of 10 billion Euro per year [33].

Although all drones must be operated in strict compliance of the rules and must not create a hazard or endanger any person or property, the growing number of drones and amateur pilots is contributing to an increased risk of drone strikes.

The use of drones is generally regulated by the national aviation authority of the country. Regulation may change from one country to another. At EU level, each country has its own regulation, and the absence of a clear regulatory framework does not pave the way towards the creation of a truly European market for drones services and aircraft. Consequently, it limits the potential of this new sector of the economy, affecting the creation of new jobs and companies.

The European Commission's response to this challenge was the proposal of a risk-based framework for all types of drones operations in 2015. The framework was supposed to ensure the safe use of drones in civil airspace and create the necessary legal certainty for the industry. Different aspects, such as privacy and data protection, security, legal liability and environmental care were taken into account.

The European Aviation Safety Agency (EASA) works together with the Commission to elaborate the regulatory framework. They have established three categories with different safety requirements according to the risk [34]:

- Open (low risk): The risks involved when using this kind of drones are low. It does not require an authorisation before the flight takes place.
- Specific (medium risk) is an operation category that requires approval by the competent authority before the flight takes place.
- Certified (high risk) is an operation category that, considering the risks involved, requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate level of safety.

The proposed regulation defines the technical and operational requirements for the drones. The standard CE (Conformité Européenne, meaning European Conformity) mark will be accompanied by the identification of the type of drone, and a leaflet of the drone's operations and procedures will be found in all drone boxes sold in the European Union.

The proposal allows a high degree of flexibility for Member States since they will be able to establish zones in their territory where either drones operations are prohibited or restricted, or where certain requirements are alleviated.

The public consultation period will finish on the 12 August 2017 and EASA will submit a final Opinion to the European Commission at the end of 2017.

2.3.1 Lithuanian regulation

In Lithuania, the Civil Aviation Administration of Lithuania (CAA) provides the state regulation, supervision and control in aviation. Drones must be operated under the Regulation on the Unmanned Aircraft Operations approved by the Order No. 4R-17 "On the Approval of the Regulation on the Unmanned Aircraft Operations" of the Director of Civil Aviation Administration of 23 January 2014 [21].

Several guidelines can be drawn from this regulation about where flights are authorised:

- Do not fly an aircraft heavier than 25kg.
- Do not fly farther than 1000 m from the controller.
- Do not fly higher than 120 m (400 ft) without permission from the CAA.
- Do not fly within 1 nautical mile (1.8 km) of the Republic of Lithuania international Vilnius, Kaunas, Siauliani and Palanga airports.
- Do not fly within 3 nautical miles (5.4 km) of the Republic of Lithuania airports at the altitude of more than 200 feet (60 m).
- You must maintain a minimum distance of 50 meters from all types of vehicles, buildings and non-authorised people.

Also it is possible to find some notes about the nature of the operator's responsibility:

- The regulation stipulates the minimum flight safety provisions for the unmanned aircraft only and does not release owner or operator from any liability against the third parties, provided that their rights or vested interests have been infringed.
- Before the flight the operator must be aware of the relevant flight safety information: legal requirements, municipal provisions, meteorological situation and forecast, etc.
- The operator must maintain visual line of sight with the drone during the whole flight.
- If the operator of the drone is incapable of the effective command (aircraft control is lost) and leaves the aircraft visibility the nearest air traffic control centre shall be informed immediately.

2.4 Mobile phone systems

2.4.1 Electromagnetic radiation

Mobile telephone antennas emit radiation in the form of electromagnetic waves. An electromagnetic wave represents the transfer of energy through space. The set of all the electromagnetic waves frequencies possible forms the electromagnetic spectrum (table 2.9).

Region	**Sub-region**	**Bandwifth**	**Wavelength**
Radio	Extremely low frequency	30Hz - 300Hz	>1000 km
	Voice frequency	300Hz - 3 KHz	>100 km
	Very low frequency	3 kHz - 30 kHz	>10 km
	Low frequency	30 kHz - 300 kHz	>1 km
	Medium frequency	300 kHz - 3 MHz	>100 m
	High frequency	3 MHz - 30 MHz	>10 m
	Very high frequency	30 MHz - 300 MHz	>100 cm
Microwave	Ultra high frequency	300 MHz - 3 GHz	>10 cm
	Super high frequency	3 GHz - 30 GHz	>1 cm
	Extra high frequency	30 GHz - 300 GHz	>1 mm
Infrared		300 GHz - 384 THz	>780 nm
Visible light		384THz - 789 THz	780 nm - 380 nm
Ultraviolet	Near	789 THz - 1,5 PHz	380 nm - 200 nm
	Extreme	1,5 - 30 PHz	200 nm - 10 nm
X-Rays		30 PHz	<10 nm
Gamma Rays		>30 EHz	<10 pm

Table 2.1: Electromagnetic spectrum

The electromagnetic radiation emitted by the antennas of phone mobile is in the region of the electromagnetic spectrum microwave networks. In particular, base stations use different frequency bands within the region of microwave (table 2.2).

System	**Bandwidth**
2G/GSM900	925 MHz - 960 MHz
2G/GSM1800	1805 MHz - 1880 MHz
3G/WCDMA	900 MHz - 2100 MHz
4G/LTE	1800 MHz - 2600 MHz

Table 2.2: Network coverage

2.4.2 Spectrum management

Radio frequencies are limited property and managed by the state. Modern society needs to use the most advanced electronic communications services. This fact ever more increases the demand for radio frequencies. From mobile phones to TV programmes, broadcasted via wireless Internet, the frequency spectrum is an important part of our everyday life.

The rapid development of the technology and convergence of electronic communications, media content and electronic equipment creates an extraordinarily dynamic environment, where the importance of the frequency spectrum as a resource must be taken into account.

The main purpose of spectrum management is to allow business and society to use the advantages, provided by the new dynamic communication environment. Effective management of radio frequencies is a requirement for the development of the new technologies.

The Communications Regulatory Authority of the Republic of Lithuania is an independent national institution. They regulate communications sector in Lithuania. It was established under the Law on Telecommunications and the provisions of the European Union Directives. Among the main activities of the institution, one can find the radio spectrum management and supervision. [37]

Cellular networks operate on different frequency bands including the 800 MHz band, 900 MHz band, 1800 MHz band, 2100 MHz band, and 2600 MHz band. In the figure 2.9 it is possible to see how the cellular network frequencies are established in Lithuania (updated in 2014)

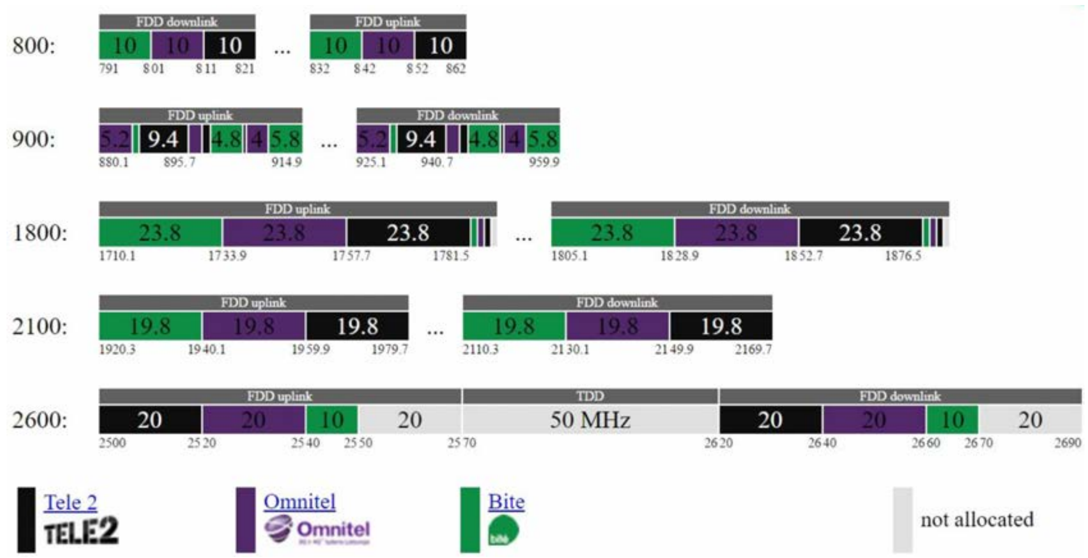


Figure 2.9: Lithuania mobile bands assignments

2.4.3 Classification system

The classification system that is more commonly used to refer to mobile communications systems is as follows:

- First generation 1G or analog (AMPS, NTM, TACS...)
- Second generation 2G or digital (GSM).
- Advanced second-generation 2.5G (GPRS) and 2.75G (EGPRS).
- Third generation 3G (UMTS).
- Third generation advanced 3.5G (HSDPA), 3,75G (HSUPA) and 3.8 - 3.85G (HSPA).
- Fourth-generation 4G (LTE) 4G+ (LTE Advanced).
- Fifth-generation 5G (without standard).

First generation (1G)

1G systems first appeared on the market in 1979, but its expansion was not very uniform. This first standard was built on analogue electronics, and it was only for voice.

The most important technology of this generation was AMPS (Advanced Mobile Phone System), developed in the United States in 1983. It was the first mobile telephony standard. In Japan, several systems were implemented by NTT: TZ-801, TZ-802, TZ-803 [17].

In Europe, there were several systems too:

- NMT (Nordic Mobile Telephone) in Denmark, Norway Holland, etc.
- TACS (Total Access Communications System) in the United Kingdom and Spain.
- C450 in East Germany, Portugal.
- Radiocom 2000 in France.
- RTMI in Italy

Second generation (2G)

The limitations of the first generation system led to the development of a new system (second generation), which was presented at the beginning of the 90's.

The new system introduced protocols of digital telephony, allowing more links simultaneously in the same bandwidth. Analogue systems did not fully use the signal between the phone and the cellular network. Analogue signals could not be compressed and manipulated as easily as a digital signal. Furthermore, it was possible to integrate other services, such as SMS (Short Message Service), and a greater ability to send data from fax and modem devices. Several standards were developed:

- GSM (Global System for Mobile Communications).
- TDMA (also known as TIA/EIA136 o ANSI-136).
- DAMPS Digital Advanced Mobile Phone System.

GSM soon became famous worldwide. It is a fully digital telephone system that supports voice, text messaging, data (9.6Kbps) and roaming. GSM is the most extended telecommunication standard worldwide. In 2008, 82% of the devices supported this standard; more than 3000 million users in 159 countries [17].

First GSM-900 networks started to work in 1992. Nokia developed Nokia 1011 (figure 2.10, which was the first mass-produced GSM phone. The launch date was 10th November 1992.

Figure 2.10: Nokia 1011

Advanced second-generation 2.5G

GSM networks have some limitations for data transmission: The transfer speed is only 9.6 kbps and roaming services are not very reliable. The slow transfer speed limits the amount of services that a user can receive and it is not possible to surf the web successfully.

GPRS is the abbreviation of Global Packet Radio System. It was a new technology that shares the bandwidth using packets to implement the data transmission. GRPS does not replace but rather complements GSM. With GRPS, transfer speed was increased to 40-110 Kbps.

Third generation (3G)

3G is the third generation of wireless mobile telecommunications technology. The International Telecommunication Union supplied a series of specifications in the International Mobile Telecommunications-2000 (IMT-2000), which is the global standard for 3G. It has applications in wireless voice telephony, mobile Internet access, fixed wireless Internet access, video calls and mobile TV.

In Europe and Japan, the standard UMTS (Universal Mobile Telecommunication System) was selected, based on W-CDMA technology. UMTS is managed by the Organization 3GPP, also responsible for GSM, GPRS and EDGE. 3G telecommunication networks support services that provide an information transfer rate of at least 200 Kbps.

Third generation advanced

There are three technologies that improve the transfer speed of 3G:

- **HSDPA (3.5G):** This technology consists on the improvement and optimisation of UMTS. It increases download speed thanks to the incorporation of a new channel in the downlink and improvement of the signal modulation.
- **HSUPA (3.75G):** It is an enhancement of the standard HSDPA by applying the same techniques to the upstream channel, i.e., the use of a new shared channel and improvement of modulation.
- **HSPA+ (3.8G, 3.85G):** It is a mobile phone standard to reach speeds of up to 42 Mbps download and 11.5 Mbps upload.

The following table (2.3) shows a summary of the achievable maximum speeds on HSPA variants:

Name	Download speed	Upload speed
HSDPA	14,4 Mbps	384 Kbps
HSUPA	14,4 Mbps	5,76 Mbps
HSPA+	42 Mbps	11,5 Mbps

Table 2.3: Achievable maximum speeds on HSPA variants

Fourth generation (4G)

In telecommunication, 4G is the acronym used to refer to the fourth generation of mobile telephony technology. It is the successor to 2G and 3G technologies and precedes the next generation, 5G.

As it had done before, the International Telecommunications Union (ITU) established a Committee to define the specifications in March 2008. This Committee is the IMT-Advanced, and it describes the necessary requirements for a standard to be considered 4G generation. They set peak speed requirements for 4G service:

- At 100 Mbit/s for high mobility communication (such as from trains and cars).
- At 1Gbit/s for low mobility communication (such as pedestrians and stationary users).

The recent increase in the use of mobile data and the emergence of new applications and services have been the reasons behind developing the LTE standard (Long term evolution).This way, a system capable of significantly improving the user experience with total mobility is designed. It uses the Internet Protocol (IP) for any type of traffic data from end to end with a good quality of service (QoS) and, in the same way, voice traffic, supported in voice over IP (VoIP) allowing for a better integration with other multimedia services.

Fifth generation (5G)

In telecommunications, 5G is an acronym used to refer to the fifth generation of mobile telephony technology. It is the successor of 4G technology. Currently there is no standard for 5G deployments, and telecommunications companies are developing their prototypes. The use of 5G is planned for 2020 although a delay is expected in its deployment.

5G planning aims at a higher capacity than current 4G, allowing a higher density of mobile broadband users, and supporting device-to-device, ultra reliable, and massive machine communications.

5G research and development also aims at lower latency than 4G equipment and lower battery consumption, which is an important point for better implementation of the Internet of Things (IoT).

2.4.4 Global System for Mobile Communication (GSM)

GSM is the telecommunication standard most extended worldwide. GSM radio interface has been implemented in different bands of frequency 850, 900, 1800, and 1900 MHz. The 900 Mhz band was born in Europe and is the most widespread.

GSM architecture consists of three elements:

- **Mobile Station (MS) or Mobile Equipment (ME):** It corresponds to the mobile device, where the SIM card is located. It stores specific information used to authenticate and identify the customer network
- **Base Station Subsystem (BSS):** It is also called 'radio network', and contains all nodes (antennas) and functionalities that are necessary to wirelessly connect mobile subscribers over the radio interface to the network. There two important elements: The Base Transceiver Station (BTS), and the Base Station Controller (BSC).
- **Network and Switching Subsystem (NSS):** It is also called 'core network' and corresponds to the mobile station. This system can give service to a fairly large area (in a radius of up to 200 kilometres) and is in constant communication with BSCs, providing rationalities necessary for switching of calls, subscriber management and mobility management.

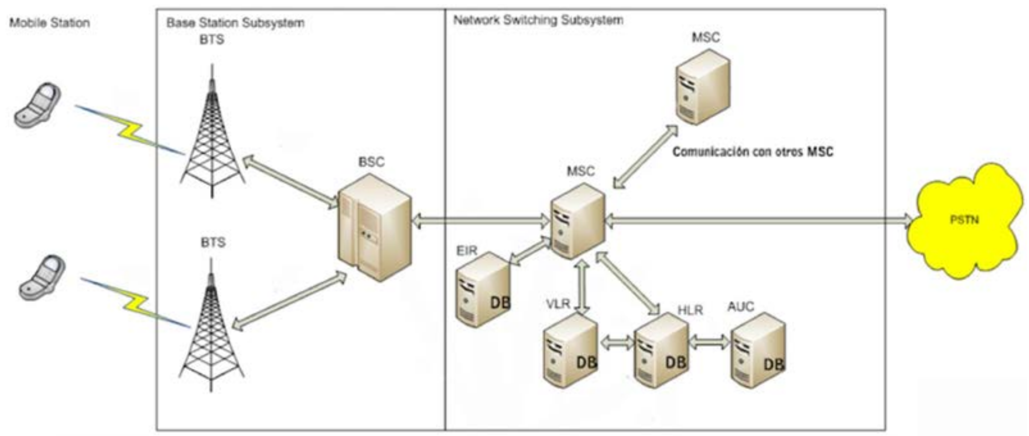


Figure 2.11: GSM architecture topology

In any system of emissions, bandwidth should devise techniques to optimise the use of a limited resource. The GSM system establishes the distribution of the channel or division of access to combine different models of allocation of the available spectrum.

To allow the base station to communicate with several mobile stations simultaneously, two methods are used. The first method is frequency division multiple access (FDMA), which means that users communicate with the base station on different frequencies. The second method used is time division multiple access (TDMA).

The use of a cellular system has clear advantages in GSM system by reusing frequencies. The downside is the large number of antennas necessary to cover the deployment of the company.

The reuse of frequencies allows a large number of users to share a limited number of channels available in the region. This is accomplished by assigning the same set of frequencies to more than one cell [17].

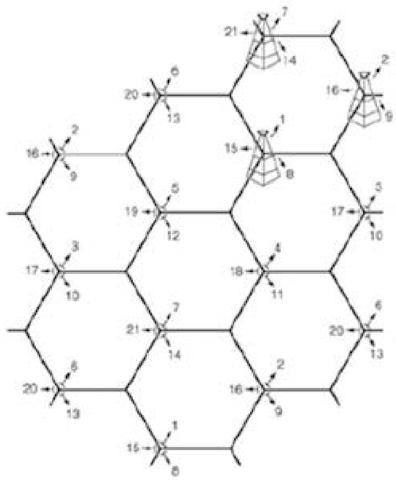


Figure 2.12: Representation of trisector

2.4.5 Mobile network and antennas

A cell is a geographical area of coverage provided by a base station. The hexagonal form was chosen because it provides the transmission with a more effective approach than with a circular shape and allows others to join without leaving gaps. A cell is defined by its physical size, but also by the amount of traffic number of current users in a particular area:

- **Macrocells:** They are present in rural, urban, suburban areas, and roads. They cover several areas (1,5 - 20 km). In this case, the antennas typically have omnidirectional coverage.

- **Microcells:** They are located in urban areas. They provide up to 1 km of coverage. With the micro-cells the technique of trisection is used (figure 2.12). It consists in dividing the cell into three zones, known as sectors. For practical purposes, they operate as independent cells. Antennas emit a range of 120°.

- **Picocells:** They are installed in interior areas with great density, such as airports and shopping malls. The coverage is up to 250 meters.

- **Femtocells:** They can be placed in homes or businesses, and they extend their coverage indoors.

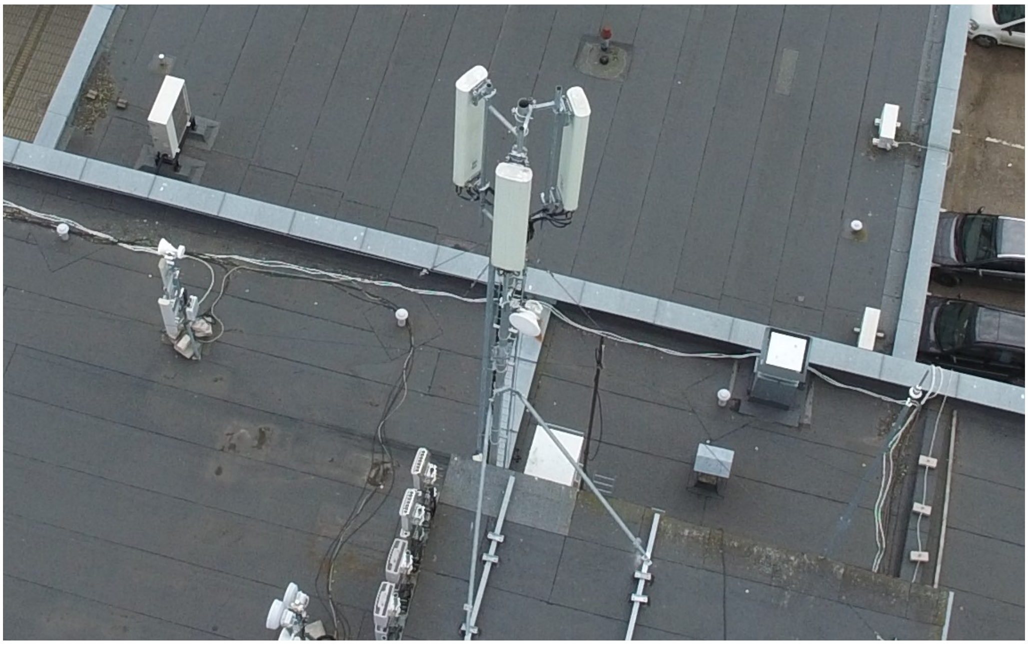


Figure 2.13: Sectoral antenna installed on KTU Faculty

Concerning microcells, a typical antenna is composed of one or more "sectoral" antennas (usually 3). Each sectoral antenna (figure 2.13) concentrates its emissions forward and horizontally, in the form of a substantially flat beam, and covers a sector between 60 and 120 degrees (figure 2.14). Emissions are almost non-existent in the rest of the directions (behind, below and above).

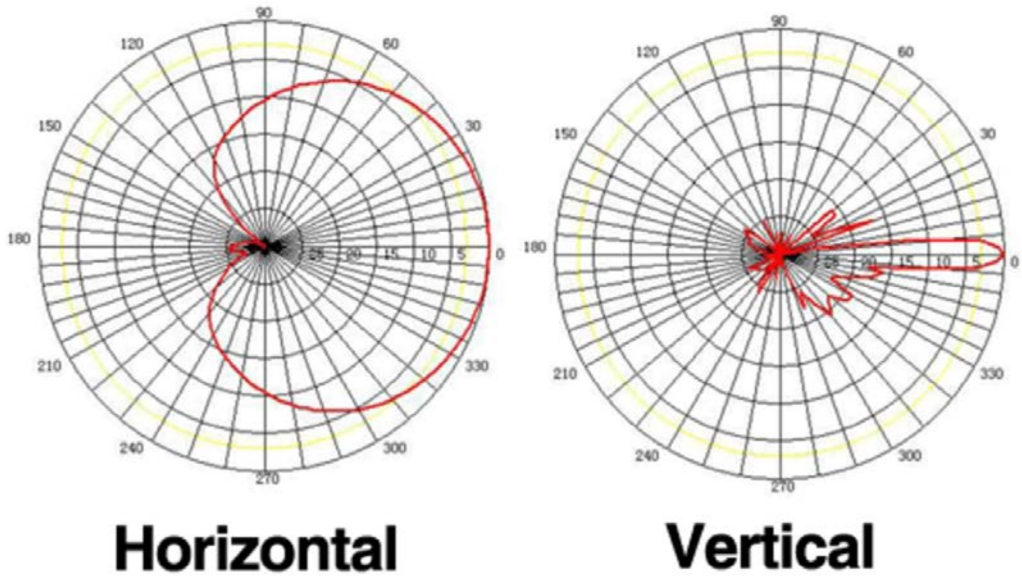


Figure 2.14: Sectoral antenna pattern diagram

2.4.6 Radio propagation models

In theory [39], the high-frequency radiation would decrease under a reverse square law, which means that the intensity of radiation varies inversely with the square of the distance from the source. If the distance from the radiation source two times is increased, the radiation intensity is reduced by a factor of four.

However, in practice, the high-frequency radiation almost never decreases as a simple function of distance, due to reflections, broadcasts and diffractions caused by interactions with buildings, trees, construction materials, etc. These effects can lead to great variability in the intensity of radiation found from one part to another in the area of measurement. In figures 2.15 and 2.16, it is possible to see reflections of microwave radiation in an urban environment.

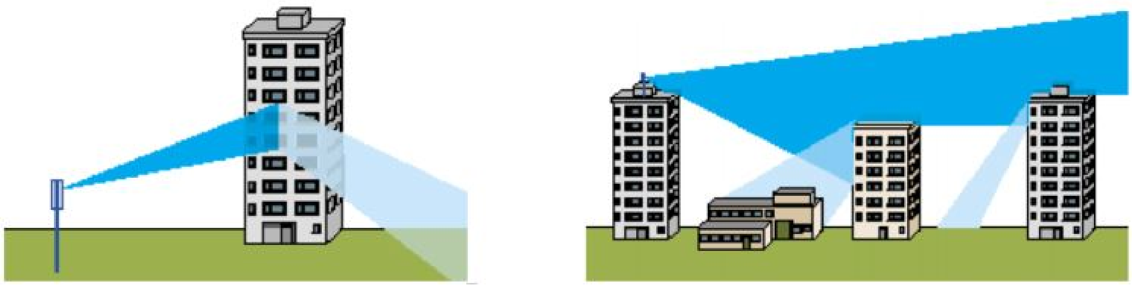


Figure 2.15: Reflections of radiation microwave in an urban environment

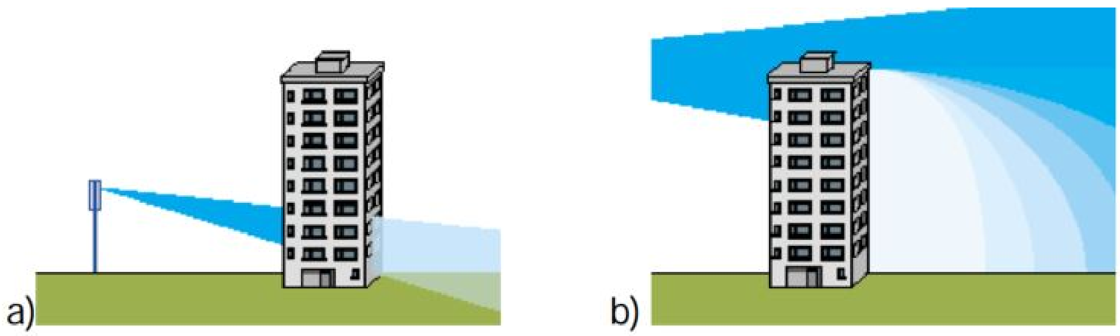


Figure 2.16: Absorption (a) and (b) diffraction radiation microwave of buildings

There are many radio propagation models known for wireless communications that predict the signal-strength loss. There are three models used for wireless networks [39]:

- **Free space propagation model:** Transmitter and receiver are in the line of sight, and there are no obstacles between them. A simplified model can be defined as:

$$P_r(d) = C_f \frac{P_t}{d^2}, \tag{2.1}$$

where P_r is the received power, C_f is constant depending on the transceiver, P_t is transmitting power and d is the distance distance between the antenna and the receiver.

- **Two-Ray ground model:** This model adds reflection to the previous model. A two-ray ground model receiver receives two rays: direct communication ray and reflected ray. A simplified model can be defined as:

$$P_r(d) = C_f \frac{P_t}{d^4} \tag{2.2}$$

- **Log-distance model:** This model has been derived from analytical and empirical methods. It can simply be defined as:

$$P_r(d) = C_f \frac{P_t}{d^\alpha}, \tag{2.3}$$

. where α is the called distance-power gradient.

2.4.7 Handovers

As it was reviewed in subsection 2.4.5 a network system is split into many small cells to provide phone signal. However, mobile phones move out of one cell to another and a procedure is required for which it is possible to keep the connection. The process is known as handover or handoff.

The process of handover within any cellular system is really important. It is a critical process and, if performed incorrectly, handover can result in the loss of the call. Dropped calls are particularly annoying to users.

The network knows the quality of the link between the mobile and the BTS. The mobile phone also knows the strength of local BTSs and their availability of channels. As a result it has all the information and it is able to make a decision about whether it needs to hand the mobile over from one BTS to another.

If the network decides that it is necessary for the mobile to hand over, it assigns a new channel and time slot to the mobile. It informs the BTS and the mobile of the change.

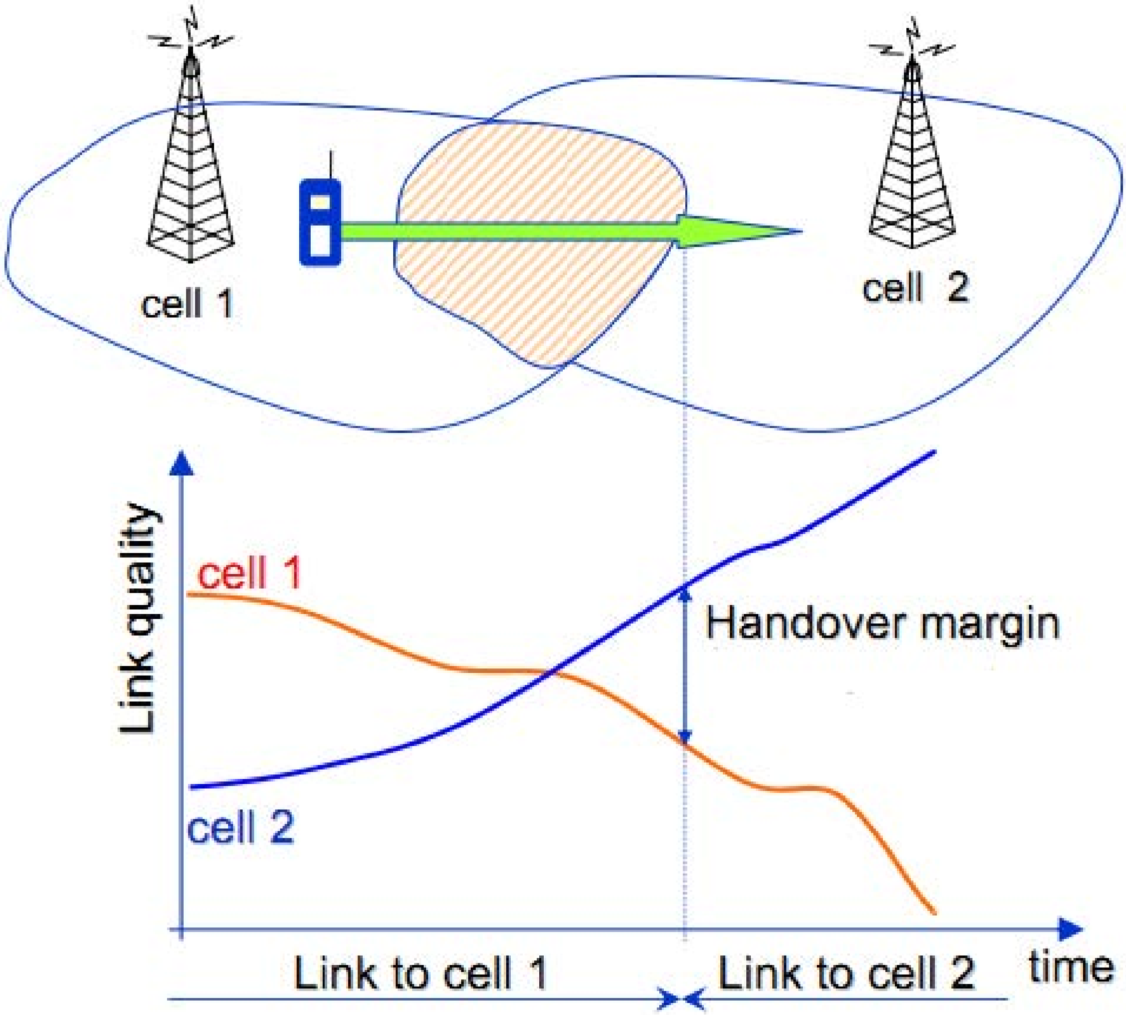


Figure 2.17: Handover procedure representation

2.4.8 Received Signal Strength Indicator

In telecommunications, received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal [17].

RSSI is signal strength indication, a measurement of how well a device can hear a signal from an antenna. Although it does not mean that it is useful for determining the "quality" or "correctness" of the signal, signal quality is usually linked to signal strength. This is because a strong signal is usually less affected by noise.

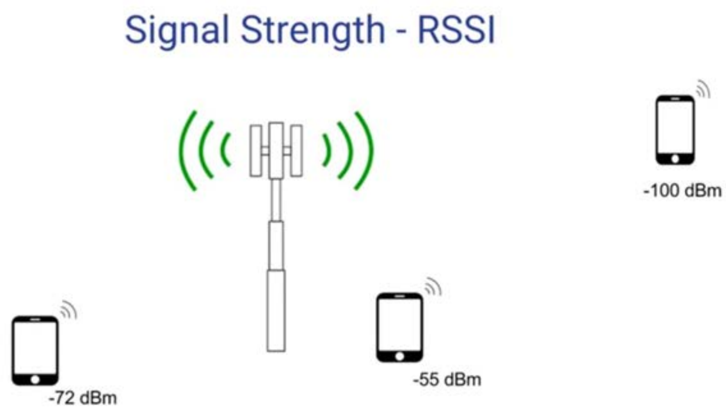


Figure 2.18: RSSI example

RSSI is measured in dBm. dBm stand for decibels relative to 1 milliwatt. dBm is used in field of radio networks to represent transmit/receive power.

As it was reviewed before, several factors might impact signal strength. If we go closer to a cell tower, the signal strength will be higher. It also depends on antenna systems, the device and signal noise or interference.

RSSI	Signal Strength
>- 70 dBm	Excellent
-70 dBm to -85 dBm	Good
-86 dBm to 100 dBm	Fair
<-100 dBm	Poor
-110 dBm	No signal

Table 2.4: RSSI values and the corresponding signal strength

Chapter 3

State of art

Recently, the issue of the operations related to unmanned platforms has become very popular. Popularity of drone is determined by the relatively small size, the cost of construction, the great flight capability, and the exploitation and use in fields, such as photographic reconnaissance, surveillance of urban traffic, evaluation and warnings in the case of disasters and unexpected events, and ecological and agricultural applications.

Although drones have military origins, they have lately been used more and more for civilian purposes. The great technological development, the cost of electronic components and economies of scale have made possible for anyone to have a drone for entertainment purposes today.

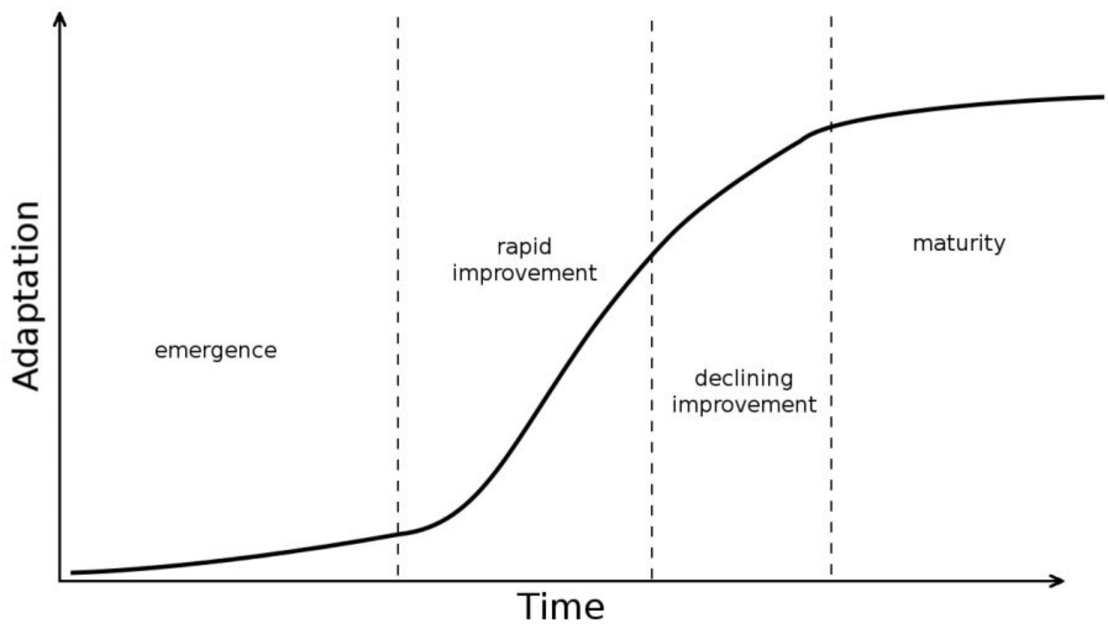


Figure 3.1: S-curve of technology

The S-curve of technology (figure 3.1) is a measure of the speed of adoption of innovation. Gabriel Tarde used it first in 1903 [25]. If we analyse how the drone's industry situation is today, we would say that we are at the 'rapid improvement' phase. The performance of technology evolves at a slow rate in the beginning but, at some point, a breakthrough happens and it improves rapidly. We are exactly at this moment. The limits of what is scientifically possible with drones are not even known today. Consequently, the future is promising.

It is the time when giants of the industry like Google or Amazon are heavily investing in research and development to create a viable commercial model. With all the improvements made, drones are becoming more agile, autonomous, power efficient and safe.

Nowadays, there is a growing interest to use drones professionally in telecommunications and industrial environments. Drones can perform surveying tasks while flying in the air quickly and inexpensively. The recent developments on the field of technology and the potential applications of drones result in an increasingly widespread use.

In this chapter, I will overview how drones are making a slow, yet steady entry into the world of telecommunications. Some examples and real cases in the following pages will show how the use of drones is a huge area for innovation

3.1 Use of drones by AT&T Company

AT&T Inc. is an American multinational telecommunications conglomerate, headquartered at Whitacre Tower in downtown Dallas, Texas. AT&T is one of the most important providers of mobile telephone services and the largest provider of fixed telephone services in the United States.

In July 2016, the company launched its programme of drones after having carried out successfully a trial [28]. It consists of telecommunications towers inspection. Autonomous drones can now gather data from cell towers and other structures at the push of a button.

Through the use of commercial drones, telecommunication operators can cut costs reducing the use of helicopters and other small aircraft to inspect assets. Drones also reduce the need, cost and danger of workers climbing telecommunications towers to perform routine audits and inspections. Furthermore, operators can identify quickly and verify tower equipment specifications and damage.

Figure 3.2: Telecommunications tower inspection

The operator merely brings the drone to the job and oversees the operation, letting the drone do the work [26]. The drone flies in a sequence ensuring it does not miss any of the cell tower's components and gathers data through sensors in the drone along with images captured by the camera. This data can be uploaded to the cloud in real time to analyse the data, allowing the discovery of any anomalies.

By enabling these unmanned inspections, the number of cell towers that can be inspected increases when compared to existing methods. Another huge advantage is that human error is taken out of the equation since people can overlook potential problems. However, analysing the data uploaded to the internet with the proper software and algorithms ensures that nothing is missed.

3.2 Wireless Aerial Surveillance Platform

Mike Tassey and Rich Perkins had the challenge of developing a low-cost aerial platform to research security weaknesses and provide recommendations for countering threats [30].

They repurposed a fuselage of an old military drone, attaching off-the-shelf and low-cost electronics and creating a spy drone. They had the capability to crack Wi-Fi passwords, eavesdropping on Wi-Fi passwords, eavesdropping on cell phone calls and read text messages.

The project utilises open-source software and they put a strong focus on system integration rather than component design. In figure 3.3 it is possible to see the system topology.

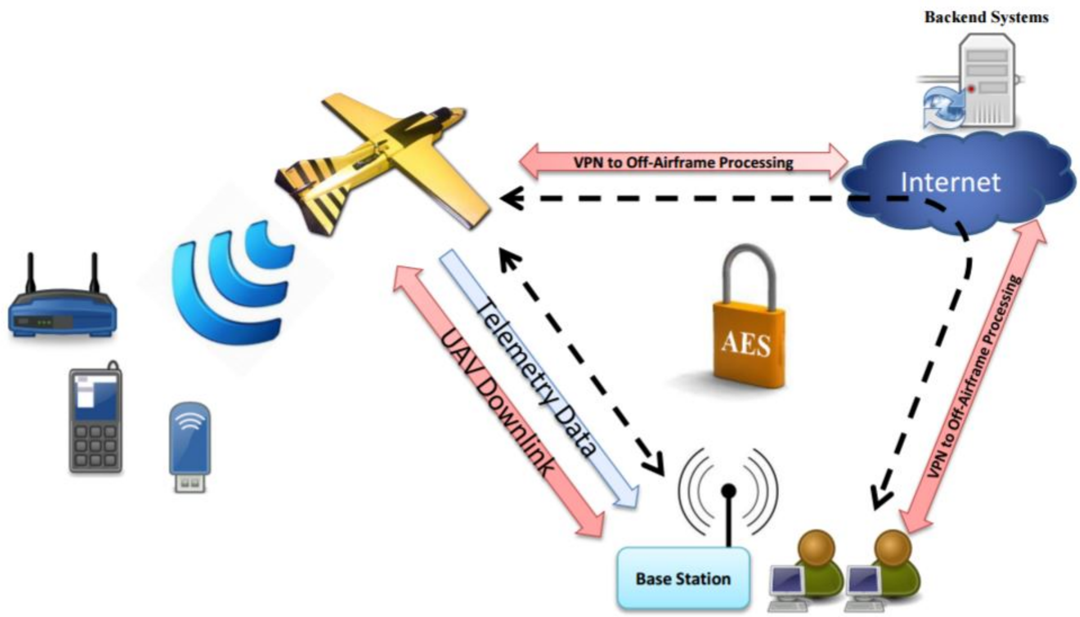


Figure 3.3: WASP system topology

Building the drone with a household budget of $6000 (€5350), they have proved that it is potentially easy to create a spy drone and use it to launch a cyber attack. The project is a proof of concept that drones could be a potential threat to privacy and security. Consequently, developing counter-intelligence is necessary today, and it can be through exploring what is possible in cyber warfare with today's readily accessible technology and being ready to combat the threat.

3.3 RF-Measurements with drones by Colibrex

Colibrex is a German telecommunications company, subsidiary of LS telcom AG which is a worldwide market leader in the provision of integrated spectrum management systems and their integration with monitoring systems [31].

The company offers specific services to facilitate the implementation, operation, maintenance and testing of wireless networks. One of the main activities of Colibrex is airborne measurement services.

Ground measurements offer useful indications about the transmitted signal. However, they have some critical limitations like reflections from the ground, buildings and vegetation.

The role of antennas in the transmission network and coverage achievement is predominant. Wrongly designed antennas or simply faulty ones (e.g. wrong installation) could cause serious perturbations with all the implications that this has for telecommunication companies.

The radiation characteristics of the broadcasting antennas should be verified in three times [32]:

1) After initial installation.
2) When modifications are performed.
3) After a certain time of use.

The problem is how to qualify and to test antennas' characteristics. The conclusion is that the only way to perform RF measurements is "on air". Some companies have been using helicopters, which is an expensive solution. Furthermore, the solution is not possible everywhere, and the measurements do not have a good accuracy.

The development of a system with drones offers new possibilities to make highly accurate airborne measurements. In figure 3.4 it is possible to see the system developed by Colibrex

Figure 3.4: Drone used by Colibrex for RF measurements

Chapter 4

Proposed system

The idea is to attach a small computer and a circuit onto a drone. The first part of the challenge proposed in this thesis is finding the components that are capable of working together as one system. The second one is making them work with each other and produce the desired results.

Some of the solutions and commercial applications available on the market produce better results than the project discussed in this thesis. Note that those projects have had larger budgets and took years of development by teams of skilled professionals. Although it is inspired by already existing projects, this project is not meant to compete with them.

This project is a demonstration of a concept intended to showcase that, thanks to the advancements in technology, open-source and open-hardware architectures, similar projects are possible with an affordable budget.

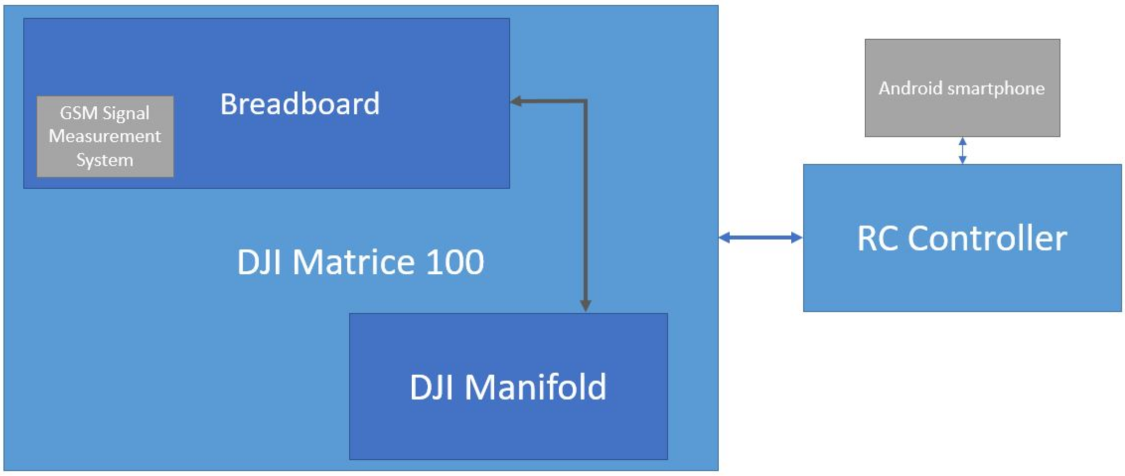


Figure 4.1: Proposed system topology

Other aspects kept in mind are modularity and compatibility. The equipment is lightweight and power efficient. Flexibility has also been taken into account: it is possible to change the sensor (e.g. humidity, pollution, temperature), modify some lines in the source code and the system would be ready for the new purpose. In summary, this project is an industrial solution for all kind of measurements with drones.

In figure 4.2 it is possible to overview the system proposed with all the installed components.

Figure 4.2: Proposed system overview

4.1 Hardware

All the components used for the execution of this thesis were provided by the FabLab Kaunas. Therefore, there was no need for personal financial contribution.

The hardware part of the project consists of these components:

- Drone
- Embedded computer
- GSM module
- Circuit

The figure 4.1 showcases the hardware connections between the different components of the system. In the following pages, they will be analysed.

4.1.1 Drone

Since precision and stability during the flight are requirements for this project, it was necessary to use a drone with the capacity to hover and perform agile manoeuvrings. Taking that into account, the DJI Matrice 100 (M100) was selected from the drones available in the laboratory.

Matrice 100 (figure 4.3) is a quadcopter developed by DJI and released in May 2015. DJI is a Chinese technology company headquartered in Shenzhen (Guangdong). It manufactures drones for aerial photography and videography, gimbals, flight platforms, cameras, propulsion systems, camera stabilisers, and flight controllers. This company is the world's leading company in the civilian drone industry, accounting for 70% of the global consumer drone market in 2017 [15].

The nominal weight of the drone is 2355g (including one battery), the dimension of the diagonal wheelbase is 650mm, and the maximum payload is 1000g. According to the specifications [18], the maximum speed 17 m/s (GPS mode, no payload, no wind) and the hovering time is 22 min (17 min carrying 500g of payload).

Matrice 100 is a stable, flexible and powerful platform capable of fulfilling many different applications. It is characterised by the multiplicity of ports and its modularity. It is a fully scalable flight platform, since it is possible to connect all types of systems or peripherals to it, from sensors to communication systems or imaging systems. It has dual parallel UART ports for connecting third-party components, such as an embedded-Linux computer.

The frame and the high landing gear have plenty of space for additional components. This drone is a perfect choice for developers and professionals who are in the process of testing sensors, processors, or are researching or innovating.

The four antennas are placed in the arms, in such a way that they are covering all four directions. The reason behind doing this is to make sure that the connection between the drone and the controller is not lost while the drone is flying [18]

It has a rigid and strong body. It is made up of carbon fibre which gives the drone strength and makes it light. It has vibration pillowed material, which helps the drone in attaining a stable flight.

No matter where the drone is landing, the four arms of the drone have a pneumatic shock absorbing landing feet, which is prepared to absorb all kind of shock and vibrations. The feet are designed in such a way that they hop and bounce while landing on a rough surface, which helps to reduce the stress on the drone.

Figure 4.3: DJI Matrice 100

4.1.2 Embedded-System Computer

In section 2.2 SBCs or embedded-system computers were reviewed. This section consists of the justification of the computer that was chosen for the present project.

Although using Raspberry Pi would have been enough (the executed program does not need special computing power), DJI Manifold (figure 4.4) was chosen because it is the computer that is available in the laboratory and it is specially designed for the use with DJI Matrice 100 and DJI Onboard SDK. DJI Onboard SDK will be reviewed in section 4.2.2.

DJI Manifold Specifications	
CPU	Nvidia Tegra K1 quad core Cortex-A15 processor 2x PRU 32-bit microcontrollers
RAM	2GB DDR3L
Storage	16GB eMMC + microSD

Table 4.1: DJI Manifold Specifications

The Manifold includes a quad-core ARM processor, similar to ones used in phones, as well as a NVIDIA Kepler graphics processor. With a size of only 11 cm x 11 cm x 2.6 cm and a weight of less than 200 g, it can be mounted easily to the expansion bay of the Matrice 100. In table 4.1 it is possible to see the specifications of Manifold.

Figure 4.4: DJI Manifold

It is equipped with USB, Ethernet, Mini-PCIe, HDMI, UART, SPI, and I2C ports. With Manifold, it is possible to connect to a wide array of sensors, monitors and other peripheral devices and also provides customised ports to connect to the Matrice 100. In the figure 4.5, it is possible to see the connections available in DJI Manifold

It is specially designed for developers, since the Manifold runs Ubuntu operating system which supports CUDA, OpenCV, and ROS. It is ideal for research and development of professional applications. The Manifold can natively run the DJI Onboard SDK, access flight data and perform intelligent control and data analysis.

Figure 4.5: Availablecconnections in DJI Manifold

The Manifold is optimised for power efficiency with a peak power consumption of approximately 15 W (one-fourth of the typical laptop's consumption). Manifold has Nvidia Tegra K1 SOC, that contains CPU+GPU+ISP in a single chip. CPU uses four A15 cores for heavy computing tasks, and a single battery-saver core when it is performing simple calculations. The number of active cores can be dynamically adjusted to decrease power consumption, and the extra core is automatically activated when it is needed. In figure 4.6 it is possible to see how computer and circuit are connected.

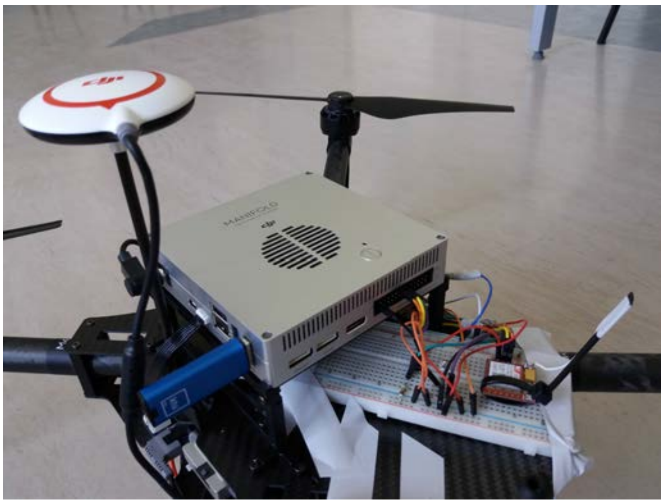


Figure 4.6: Connections between Manifold and the circuit.

4.1.3 Circuit

The following components, which are mounted on a breadboard, have been used in the circuit (figure 4.9):

1) GSM Module SIM800L
2) 1N4004 silicon diode
3) 5mm LED indicator
4) Switch push button
5) 1 kΩ resistor (Pull down)
6) 220 Ω resistor (Led protection)
7) 247 Ω resistor for Pi Attenuator
8) 2 x 68 Ω resistor for Pi Attenuator
9) Rechargeable NiMH Battery. 4.8V, 2000 mAh

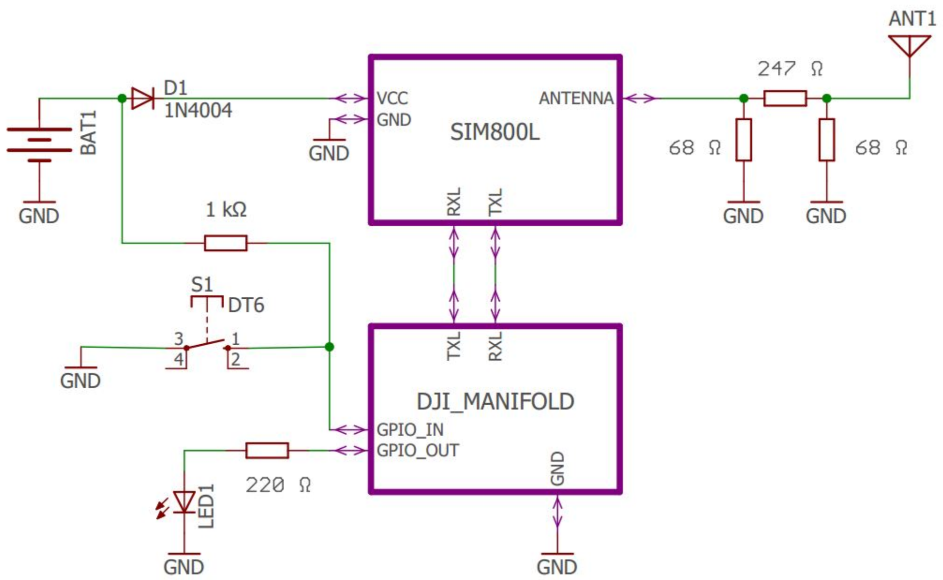


Figure 4.7: Electrical schematic

The breadboard is attached to the drone's frame, and it is located below the Manifold, that it is mounted to the expansion bay of the M100. Although a printed circuit board (PCB) could have been designed and used, it was easier mount the different components directly on a breadboard. It was a good decision since it was necessary to do some changes after doing the first experiments. These kind of changes are easier to do it with this kind of boards. Electromagnetic interferences were avoided separating the GSM module and its lines from the rest of components.

In the first attempt, 5V from an USB connection of Manifold was used as a power supply for the circuit. However, after doing some experiments in the lab, it was realized that it was necessary to use a independent power supply for this circuit. This is because of the speed of the motors, and consequently the dropped current was affecting measurements.

The silicon diode is used to reduce the voltage in the GSM module. The dropped voltage in this kind of diodes when they are conducting is 0.7 V. The NiMH battery supplies 4.8V, and putting the diode in the middle, voltage produce an output of around 4 V. According to manufacturer's specifications, a proper voltage for the module is 3.8 V - 4.4 V.

The GSM module is connected to the Manifold using Universal Asynchronous Receiver-Transmitter (UART). UART is a is a block of circuitry responsible for implementing asynchronous serial communication in which the data format and transmission speeds are configurable. Essentially, the UART acts as an intermediary between parallel and serial interfaces.

UART devices use receive (RXD) and transmit (TXD) connections to establish separate paths for sending and receiving data between multiple devices. Asynchronous communication uses a single transmitting channel to send one byte of data at a time at a specified rate [24], known as the baud rate which is measured in bits per second (bauds).

Both the led and button are the only way to interact with the Manifold when the operator is of the lab since there is not any screen to view what is happening on the computer.

Although the code will be discuss in detail in the next section, it should be underline that the program runs at start-up when the computer is switched on and is waiting until the push button installed in the breadboard is pressed to start the flight and measurement process. With the LED it is possible to know when the drone is ready to start the flight. Furthermore an error code was established in order to understand which could be the issue if the program is not starting successfully after the push button is pressed.

General-purpose input/output (GPIO) is a generic pin on an integrated circuit or computer board whose behaviour-including whether it is an input or output pin is controllable by the user at run time. In Manifold, there are two GPIO port available and they are used in connection with the push button and the LED:

The LED, which is protected with a 220 Ω resistor, is connected to the port and set as GPIO-OUT.

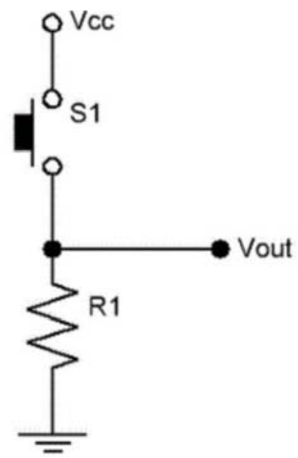


Figure 4.8: Pull down resistor configuration

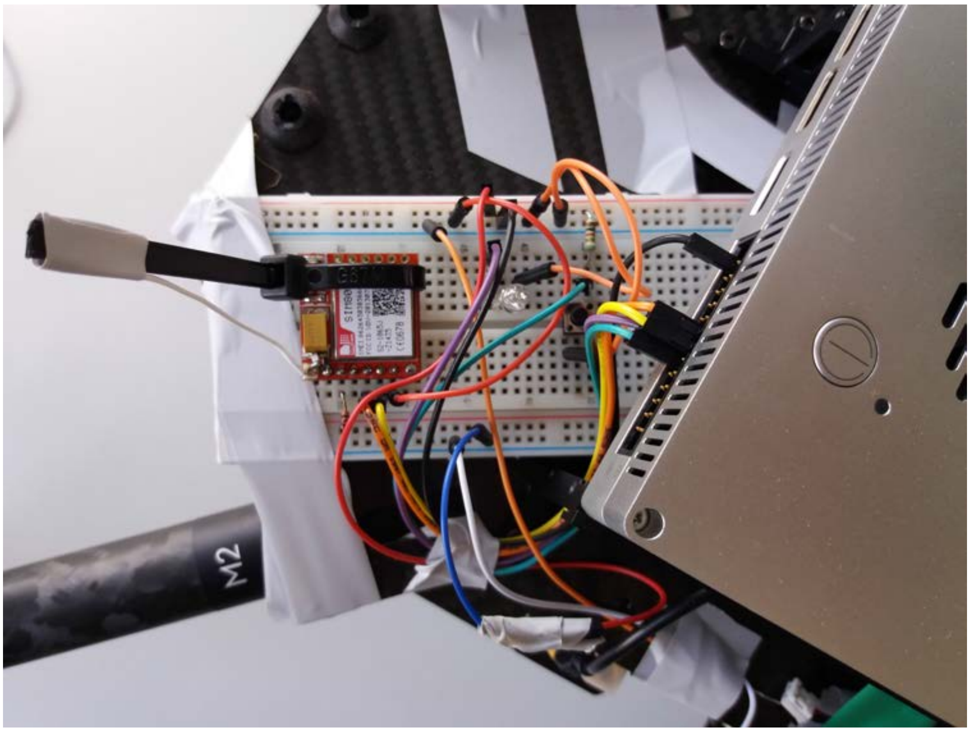


Figure 4.9: Electric circuit mounted on the drone's frame

The button is connected to the port set as GPIO-IN through a pull-down (figure 4.8) with a 1 kΩ resistor.

In figure 4.9 it is possible to see in detail the circuit mounted on the drone's frame.

Pi Attenuator

Concerning the antenna connected to the module, it was proved in laboratory test that it was too powerful. Therefore it was necessary to install an attenuator between the antenna and the port.

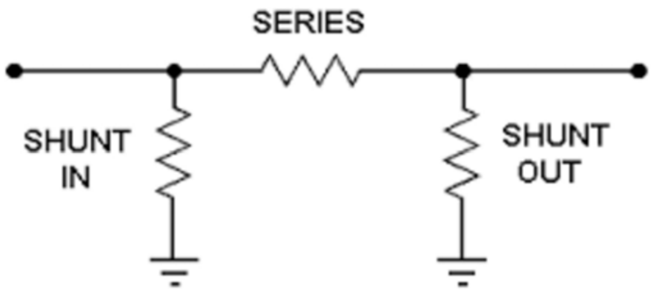


Figure 4.10: Pi attenuator diagram

An attenuator is an electronic device that reduces the power of a signal. Attenuators are usually passive devices made from simple voltage divider networks. In this project a pad (figure 4.8) is used to reduce the signal from the antenna. Three resistor were soldered directly to the module board.

In reference [27], Peter Vizmuller explained formulas necessary to calculate resistors of a Pi attenuator.

$$\text{Vout} = \sqrt{\frac{Z_{out}}{Z_{in}}} + \sqrt{\frac{1}{10^{Att \cdot 0.01}}}, \tag{4.1}$$

where V_{out} is the output voltage, Z_{in} and Z_{out} are the input and output impedance and Att is the required Attenuation.

Once the $Vout$ has been determined, it is possible to calculate the ideal resistor value:

$$\text{Ideal Shunt In Resistor} = \frac{(Z_{out} \cdot Z_{in}) - ({Z_{in}}^2 \cdot {V_{out}}^2)}{Z_{out} + (Z_{in} \cdot {V_{out}}^2) - (2 \cdot Z_{in} \cdot V_{out})} \tag{4.2}$$

$$\text{Ideal Shunt Out resistor} = \frac{V_{out}}{\frac{1}{Z_{in}} - \frac{V_{out}}{Z_{out}} - \frac{1}{Shunt_{in}}} \tag{4.3}$$

$$\text{Ideal Series Resistor} = \frac{(1 - V_{out}) \cdot Z_{in} \cdot Shunt_{in}}{Shunt_{in} - Z_{in}} \tag{4.4}$$

Considering $Z_{out} = Z_{in} = 50\Omega$ and a attenuation of 20 dB, values amended to read as follows:

-Ideal Shunt In Resistor: 61.11 Ω
-Ideal Shunt Out Resistor: 61.11 Ω
-Ideal Series Resistor: 247.5 Ω

After calculating the idea values it is necessary to find the available resistor values:

-Real Shunt In Resistor: 68 Ω
-Real Shunt Out Resistor: 68 Ω
-Real Series Resistor: 247 Ω

4.1.4 GSM Signal Strength Measurement System

The SIM800L (figure 4.11) is a Quad-Band GSM/GPRS module designed by SIMcom, which works with frequencies of 850/900/1800/1900 MHz. With this module it is possible to add voice, SMS and data (TCP/IP, HTTP, etc...) to a project. Everything is concentrated in a compact size (2.48 x 2.30 cm). Its most outstanding feature is the cost since it is possible to get it in a electronics store by ten Euro.

The module can be accessed with AT commands, which are instructions used to control modems. They belong to the Hayes command set, which is a command set in a specific command language originally developed by Dennis Hayes for the Hayes Smartmodem 300 baud modem in 1981 [23].

Figure 4.11: GSM module SIM800L

AT is the abbreviation of ATtention. Every command line starts with "AT" or "at". That is why modem commands are called AT commands. It consists of a series of short text strings which can be combined to produce commands for operations such as dialling, hanging up, and changing the parameters of the connection. They are used to control wired dial-up modems, GSM/GPRS modems and mobile phones. In the reference [22] it is possible find:

> The AT command set implemented by SIM800 Series is a combination of 3GPP TS 27.005, 3GPP TS 27.007, ITU-T recommendations V.25ter and the AT commands developed by SIMcom.

Although the purpose of this module is not the measurement of radio frequency signals, it contains two AT command with which it is possible to get the RSSI value. RSSI was reviewed before in section 2.4.8.

The first command is AT+CSQ, Signal Quality Report. The execution of the command returns the received signal strength indication (RSSI) and channel bit error rate (BER). It is possible to see the list of RSSI parameter in table 4.2. As it may be seen, the resolution of the sensor is 2 dBm; the worst value of RSSI is -115dBm and the best one is -54dBm.

Returned value	**dBm**
0	-115 dBm or less
1	-111 dBm
2...30	-110... -54 dBm
31	-52 dBm or greater
99	not known or not detectable

Table 4.2: RSSI parameter in SIM800L module

The second command is AT+CENG. The difference with AT+CSQ, is the possibility of getting data of seven antennas at the same time.

4.2 Software

The objectives of this project include the development of the necessary software for the implementation of the proposed system. The developed software is own code and is open source. The code can be found in the following link of a GitHub software repository:

`https://github.com/alvarozornoza/DroneKTU/`

DroneKTU consists on an app developed in C/C++ to control GSM signal measurements with the embedded-system computer DJI Manifold attached to the drone DJI Matrice 100.

4.2.1 License

The project is under by GNU General Public License published by the Free Software Foundation.

This is the license of copyright more widely used in the world of free software and open source, and ensures end users (people, organizations and companies) the freedom to use, study, share (copy) and modify the software.

Its purpose is twofold: it declares that the software covered by this license is free, and protects it (through a practice known as copyleft) attempts of appropriation that restrict those freedoms to new users whenever the work is distributed, modified or extended.

Although the main part of the code is own developed, DJI On Board SDK was used. It contains all the libraries and functions necessary to implement the interface between the Onboard Embedded System (OES). DJI is the only owner of next directories and their respective files that can be found in the repository: /contrib, /osdk-core, /osdk-wrapper, /platform.

4.2.2 DJI's On-Board SDK

A development kit software or SDK (software development kit) is a set of software development tools which permits software developers to create applications for a specific system, such as certain packages of software, frameworks, hardware, operating systems, computers, game consoles, etc.

It includes an application programming or API (application programing interface), interface created to enable the use of some programming language. It can also include sophisticated hardware for the communication with a certain embedded system.

DJI's onboard SDK makes possible the connection with OES, in the case of this project DJI Manifold, to a supported DJI drone, in this case DJI Matrice 100. The connection is done using a common serial port (TTL UART).

4.2.3 C++

C++ is the programming language chosen for the software part of this project. It is a programming language released in the mid-1980s by Bjarne Stroustrup. The intent of its creation was extending to the C programming language mechanisms that allow the manipulation of objects.

C++ is standardized by the International Organization for Standardization (ISO), with the latest standard version ratified and published by ISO in December 2014 as ISO/IEC 14882:2014 (informally known as C++14).

4.2.4 Linux environment

As it was reviewed before, DJI Manifold was the embedded system computer chosen. Ubuntu version 14.04 operating system was pre-installed on the computer on its delivery.

Operating systems (OS) abound and the choices are many for an embedded system, both proprietary and open source. Linux is one of these choices. Linux is open source, and it is possible to read the code in order to get an understanding of what is the OS exactly doing. It is often impossible with a proprietary OS distributed as binaries.

Programming Linux is easier than other embedded operative systems because of few factors: It is possible to find many books and tutorials about Linux. Online resources for Linux are ample, while other operative systems have a much smaller presence, or are driven by the OS manufacturer.

The most significant factor that sets Linux apart from other operative systems is that the same kernel is used for all systems, from the smallest embedded boards, through desktop systems, to large server farms.

Finally, embedded systems have to be developed in low-cost platforms and the drivers are mainly developed for Linux.

4.2.5 Business requirements

Background

The reason for this work is the requirement of the presentation of a final project to finish the bachelor. This work seeks to show all the knowledge acquired throughout the bachelor and in this case, it is a clear multidisciplinary project.

Business Opportunity

It is an educational project and it does not have a chance of real business in the short term. However, all the research and work that goes into its development could conclude in a business opportunity in the future.

Business Objectives and Success Criteria

The cost of the program was zero Euro, since the necessary libraries are open-source and provided by the company that assemblies the drone. On the other hand, the number of hours used in the preparation of the documents and the development of the code do not have an economic cost since the services of the author of this project are not paid.

Customer or Market Needs

Nowadays, there is a growing interest to use drones professionally in telecommunications and industrial environments. Drones are able to perform surveying tasks while flying in the air quickly and inexpensively.

The recent developments on the field of technology and the potential applications of drones result in an increasingly widespread use. To make this possible, it is necessary to develop these aerial platforms and its software, which is probably the most important and difficult part of a development process.

Business Risks

- The software developed is not going to be placed on the market, temporarily at least.
- The cost of the program was free of charge.

Taking both aspects into account, it is possible to check that this project does not have any business risk.

4.2.6 Vision of the Solution

Vision Statement

As it was said before, DroneKTU consists on an app developed in C/C++ to control GSM signal measurements with the embedded-system computer DJI Manifold attached to the drone DJI Matrice 100.

The development of system with drones offers new possibilities to execute highly accurate airborne measurements. This project consist on the development of a new method to measure GSM signals.

The problem of qualifying and testing antennas' characteristics can be only solved with on-air measurements. With the current development of science, drones are the best option since other methods, such as helicopters, are more expensive and less accurate.

Major Features

- The code is open-source.
- The code could be upgraded in the future to introduce improvements, since the code is well organized and object-oriented programming procedures were used.
- The system developed has some flexibility, modularity and adaptability on the matter of changing the sensor for a different purpose.

Assumptions and Dependencies

- The software can only be ran on Linux machines since specific libraries for UNIX operatives system were used.
- The software is only valid for the drone Matrice 100, that was assembled by DJI. However, it would be quite easy to implement the code for other drones and platforms if it was necessary.
- The connection between the SBC and the drones is done thanks to DJI, who wrote the necessary code.

4.2.7 Scope and Limitations

Scope of the Initial Release

Initial release complied with the requirements and specifications established at the beginning of the present project.

The program is run-time startup code. Once the computer has loaded the operative system, it is waiting until the push button placed on the breadboard is pressed to start the measurement process. The system is able to measure and save GPS coordinates, height and RSSI values in a file on an external pen-drive every half second of flight.

Scope of the Second Release

Although the initial release complied with the specifications, it was necessary to improve the first version. The delay of the GSM module and the fact that the process was manual produced the creation of the second version.

In this version, the flight is autonomous. After switching on the computer, once the LED is on, the system is ready to fly. After the push button is pressed, the operator has 10 seconds to go away within the minimum security distance (around ten meters) before the drone takes off. The operator only needs to supervise the process as a risk prevention way.

The drone lifts up to 100 meters. The drone is measuring height and RSSI values twenty times every five meters. The program calculates the average and standard deviation of the values and saves those them on a file. The file is saved on an external pen-drive since it is easier to analyse the experiments on the field, with another computer, such a laptop. In this way, any further delay, like the transport time to the laboratory, is removed.

Scope of the Third Release

This version is very similar to the second release. In instead of getting information of only one antenna, a new command is incorporated (AT+CENG?) with which it is possible to get information of seven antennas at the same time.

Scope of the Fourth Release

This version includes two flight modes. The first one is the developed in version 2.0 and 3.0. The second mode consist on the flight over a football field. A sort of matrix of points is made where the signal strength is measured. Although the mode two was fully developed, there was not enough time to test it.

Limitations and Exclusions

As it was written before, the developed software can be only run with DJI Matrice 100 and Linux platforms.

4.2.8 Design Class Diagram

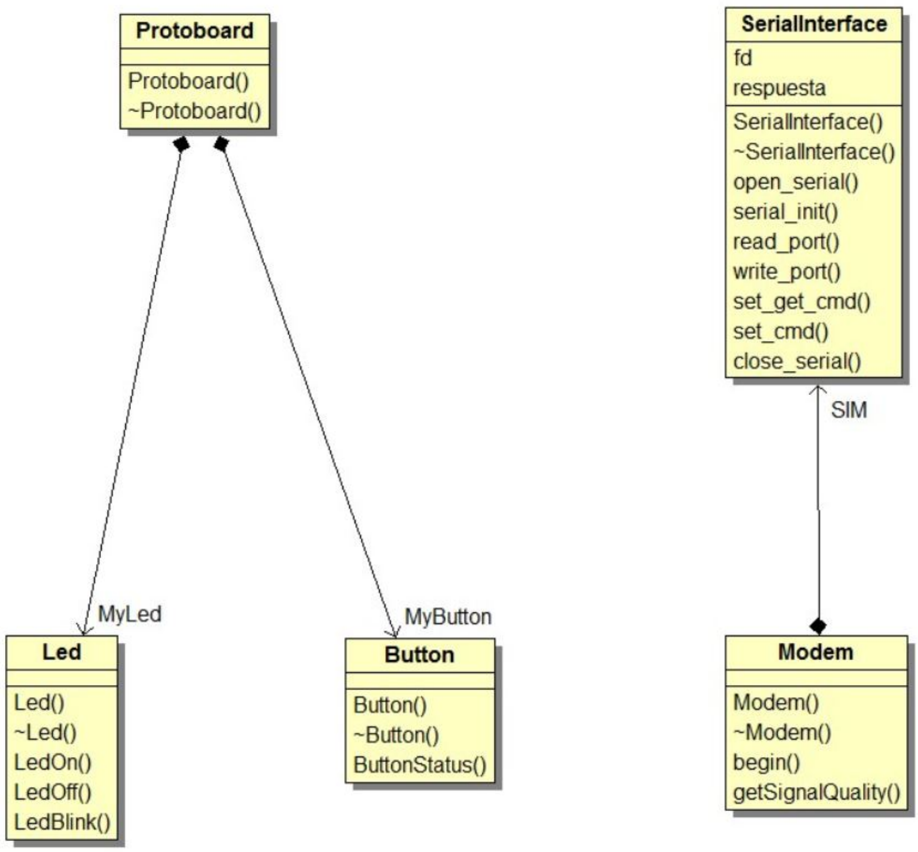


Figure 4.12: Design class diagram

In figure 4.12, it is possible to see the Design Class Diagram that includes the classes developed in the present project. A summary of classes' features is presented below:

Protoboard

The class Protoboard refers to the Breadboard mounted on the drone's frame. As it was reviewed before, it contains one LED and one button. It possible to see it in the diagram (figure 4.12).

Led

The class LED manages connection and operation of the led installed in the breadboard. The connection is done through GPIO-OUT port available in the SBC.

This class includes several functions to both switch on and switch off the LED. Blinking mode is possible too.

Note that in Ubuntu it is necessary to have administrator user permissions to manage GPIO ports.

Button

The class LED manages connection and operation of the button installed in the breadboard. The connection is done through GPIO-IN port available in the SBC.

This class has a function to detect the button status which is the signal sent out to start the process.

Note that this button was also used to finish measurement process in the first version of the developed software. There were some problems concerning the button's bouncing. It was fixed by programming some for-loops, in order to make sure that the button was actually pressed.

SerialInterface

The class SerialInterface contains all the necessary functions to manage a serial connection.

The developed functions include several features, such as the initialization of the serial device, read and write operation and the termination of the serial communication.

Modem

Modem class inherits characteristics of the class SerialInterface. It includes the specific functions to manage the GSM module and submit of AT commands, reviewed in section 4.1.4.

4.2.9 Software notes

Measurement.cpp and Measurement.h files do not belong to any class but contain necessary functions to execute measurement process including features, such as data acquisition and average and standard deviation calculation.

The main file of the project is called DroneKTU.cpp and it is located in drone directory. It calls all the necessary functions to connect to the drone, the breadboard and GSM module. It also manages the opening and writing operations of the file saved in the external pen-drive.

As it was said before, the program is a run-time startup code that is waiting until the push button is pressed. Once the button is pressed, the main process starts. It includes the take-off, measurements and manoeuvring of the drone, and the landing in the same point. In figure 4.13, it is possible log data from OSC shown at the screen.

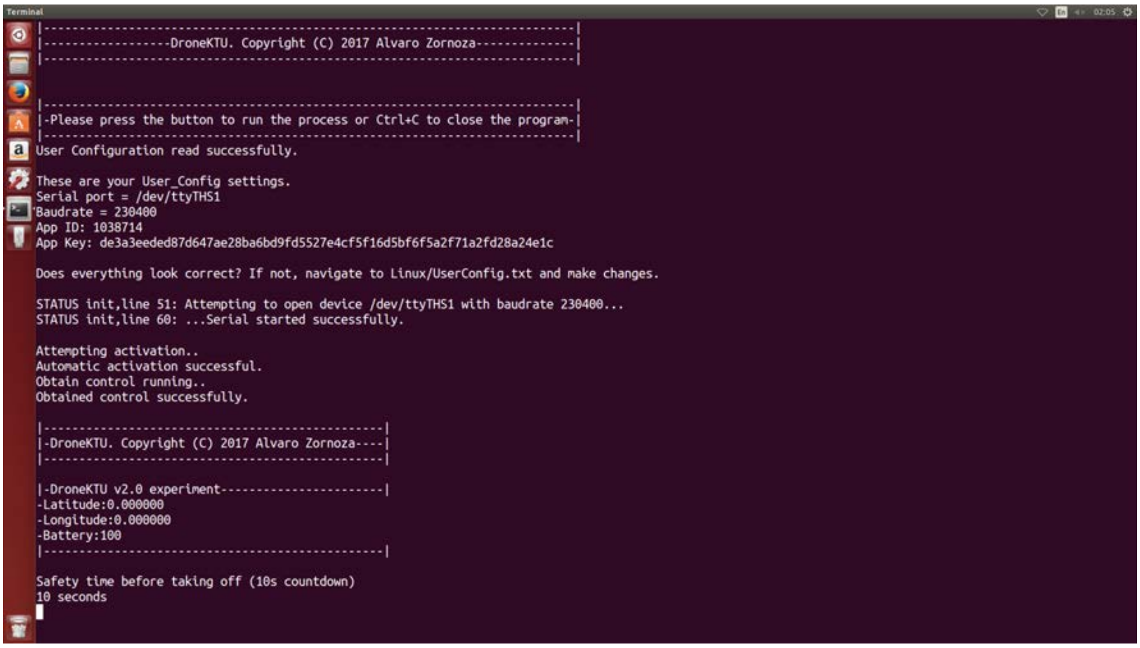


Figure 4.13: Log data after pressing the button

To start the process it is necessary to comply three conditions as it is possible to see in figure 4.15.

1. Successful connection with GSM module
2. Drone and controller have to be switched on. Controller has to be in F mode. Intelligent Orientation Control (IOC), API Control, and other functions are supported in this mode.
3. Pen drive has to be connected to the OSC in order to create the file.
4. Battery level has to be above 40%.

The drone would land automatically if it has a low battery level because of DJI protocol based on security reason. Even so, battery checking is included in the code. If the battery level was less than 40%, the process would never start.

The flight and measurement process includes the drone lifting up of the drone up to 100 meters. The drone is measuring height and RSSI values twenty times (frequency of 2 Hz) every five meters. The program calculates the average and standard deviation of the values and saves the data on a file. In figure 4.14, it is possible to see an example of how the program saves the measured data.

```
25-05-17_09.35: Bloc de notas
Archivo  Edición  Formato  Ver  Ayuda
|----------------------------------------------|
|-DroneKTU. Copyright (C) 2017 Alvaro Zornoza----|
|----------------------------------------------|
|-DroneKTU v2.0 experiment----------------------|
|-Latitude:54.904533 -Longitude:23.957774 -------|
|----------------------------------------------|

Height_avg;Heigh_sd;RSSI_avg;RSSI_sd

4.777867;0.030038;-72.000000;3.464102
10.034054;0.028659;-59.100000;0.994987
14.982664;0.060755;-63.900000;0.435890
20.050342;0.067960;-59.000000;2.408319
25.044785;0.045110;-63.000000;1.000000
29.963089;0.092618;-60.000000;0.000000
35.078653;0.072183;-58.000000;0.000000
40.134431;0.098982;-60.000000;0.000000
44.949249;0.119423;-58.000000;0.000000
50.029938;0.059281;-63.500000;0.866025
54.949999;0.092290;-62.000000;0.000000
59.994103;0.073912;-60.600000;0.916515
65.021004;0.058325;-64.000000;0.000000
70.004031;0.059807;-64.000000;0.000000
74.923844;0.074287;-66.000000;0.000000
80.108873;0.048499;-64.800000;0.979796
84.988396;0.198502;-62.500000;0.866025
89.960785;0.050285;-65.100000;0.994987
95.056204;0.045787;-66.000000;0.000000
99.938651;0.049093;-68.000000;0.000000

Experiment runned sucessfully.
```

Figure 4.14: Example of an experiment file

Note that before measuring, the drone is waiting 10 seconds because of the delay of the GSM module that was discovered during the first experiments in the laboratory. Once the measuring process finishes, the drone is landing autonomously in the same location from it takes off. Finally the drone is disarmed and all the connections are finished.

Although the battery is only allow to supply energy for one experiment, the drone is waiting until the button is pressed to start the process again. It would be possible if a better battery was available or another battery was mounted on the drone.

4.2.10 Flow chart

Two flow charts about version 2.0 of the developed software are presented in this section. The first one (figure 4.15) consists of the error-code during the management of connection phase before starting the measurement process:

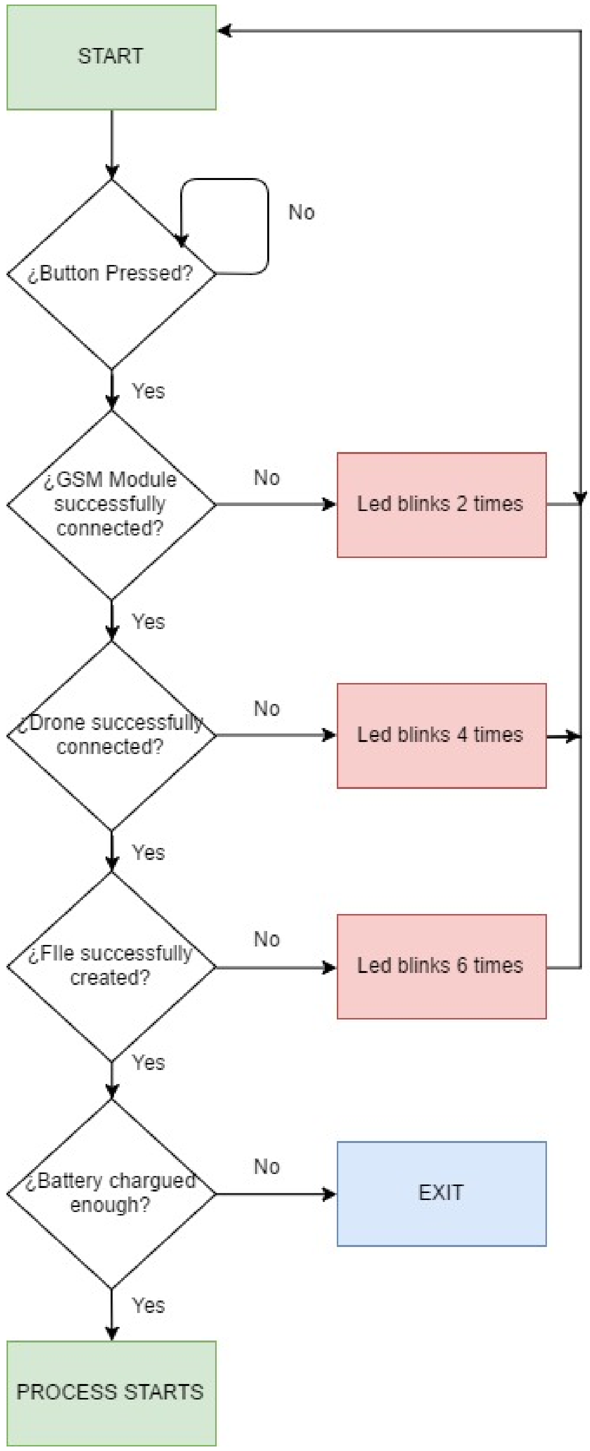


Figure 4.15: Error-code flow chart

Once the button is pressed and all the connections are done successfully, the drone is ready for the taking of. The flowchart of the main process in figure 4.16 could help to understand the procedure.

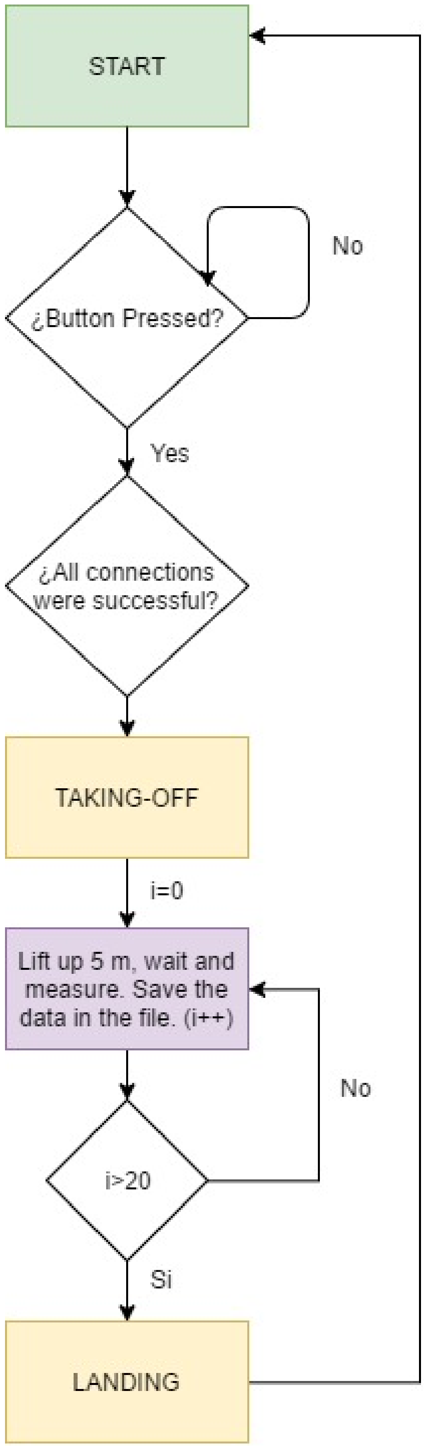


Figure 4.16: Main-process flow chart

Chapter 5

Experimental flight procedures

This project includes the development of the system and the subsequent real test with different experiments. DJI provides safety guidelines about the battery [35]:

1. Detach the battery when the drone is not being used.
2. Connect the battery charger to a suitable power supply (100-240V 50/60Hz). The charging temperature range is 0 to 40 °C.
3. Do not leave the battery charging without supervision.
4. Air cool the battery after each flight. Temperature must drop to room temperature before charging.

Before the real-life experiments, it was necessary to test the developed software and different hardware parts with the drone switched on and armed in the laboratory. Detaching the propellers from motors when the drone is in the lab is an important rule to follow in order to prevent risk and damages. Actually, propellers must be attached and detached before and after the flight respectively.

In figure 5.1, it is possible to see Kaunas Air Space and where KTU campus and the Faculty of Electrical and Electronics Engineering are located. It is easy to check that it is quite far from Kaunas Airport (more than 3 NM). Therefore, the altitude limitation is 120 m. All the experiments were done flying under 120 m with a drone with a weight of about 3 kg. That means that current legislation on drones in Lithuania was followed completely.

Figure 5.1: Kaunas airspace map

A methodical set of procedures will help ensure that no disasters occur due to a non-intentional oversight. The preflight check-list used before flights is the following (about software version 2.0 - autonomous flight):

1. Remote controller, drone and smart phone batteries are fully charged.
2. Check that all the elements of the drone and the payload (computer, breadboard, 4,8V battery) are correctly attached.
3. Attach the camera if it is going to be used during the flight and make sure that it is firmly attached.
4. Connect breadboard with 4,8V battery and ensure that the led from GSM module is blinking.
5. Attach the propellers and make sure at least twice that they are correctly mounted.
6. Switch on the controller and connect the mobile phone
7. Switch on drone battery ensuring that the link with the controller is successfully established.
8. Switch on the Manifold computer and wait until the led in the breadboard is on.

Once the LED is on, the system is ready to fly. Since the moment that the push button is pressed, the operator has 10 seconds to go away the minimum security distance, around ten meters, before the drone takes off.

Although the program is developed to run an autonomous flight, the operator must maintain visual line of sight with the drone and supervise the whole flight.

DJI protocol establishes that the drone can be controlled by:

1. Remote controller.
2. Mobile device
3. On-board Embedded System (Manifold computer)

The priority is set as (1) > (2) > (3). This is done to prevent the dangerous situation that would arise if the code failed and the user were not able to take back control of the drone and shut it down. The remote controller always enjoys top priority for control [36].

In the present project, the drone is controlled with Manifold but the operator can take the control of the drone in any moment of the flight with the controller if something is wrong or there is a certain of a possible accident.

The program developed includes the take-off, measurements and manoeuvring of the drone, and the landing in the same point. Operator has to be particularly focused during the last 20 meters of the landing phase, making sure that the drone is landing in the correct area. Note that the controller beeps during the whole phase of landing.

Once the drone has landed, the first action is to switch off the drone and disconnect the flight battery. Post-flight maintenance includes the air cooling of the battery before charging and a brief inspection in order to see if there are any issues that will require attention before the next flying session.

Chapter 6

Experiments and numerical results

Appealing as it may seem, using the drone for testing purposes was less than convenient. There is a lot of downtime between flights to charge the batteries. The drone and the RC transmitter are bulky and heavy to carry in and out of the building. In the five months that this project has lasted, numerous experiments were executed and allowed the detection of failures and weak points, and the improvement of the developed software.

It would be impossible to talk about all the experiments (more than 5 hours of flights and experiments were done). Therefore, only recent experiments will be discussed.

For those experiments, version 3.0 of the software (different releases of the software are explained in section 4.2.7) was used. The experiments consisted on the execution of the measurement process in eight different position. The data of the two most powerful antennas is filtered and analysed. Then the maximum, minimum and average values of the received signal strength indicator from the different positions are plotted and analysed. Finally, it is possible to find GSM signal strength maps for both antennas.

Since the measuring equipment is low-cost and not specially designed for measurements, the units are arbitrary. The device can be calibrated using a more precise and professional equipment.

6.1 Location of antennas and measurement points

In order to decide the measurement positions, it was possible to measure the available antennas close to the laboratory. In figure 6.1, it is possible to see the map with the location of the GSM antennas that the drone is connected to.

The map was elaborated with Google Maps API and the information was obtained from OpenCellID, which is "the world's largest Open Database of Cell Towers". It could be found in the following link: `https://opencellid.org/`

Although the information that could be obtained from this database is really valuable, note that it is not an official information. Therefore, it is not reliable and it could be not accurate.

The author of the present project tried to get official information from the company Omnitel of location of GSM antennas without any success.

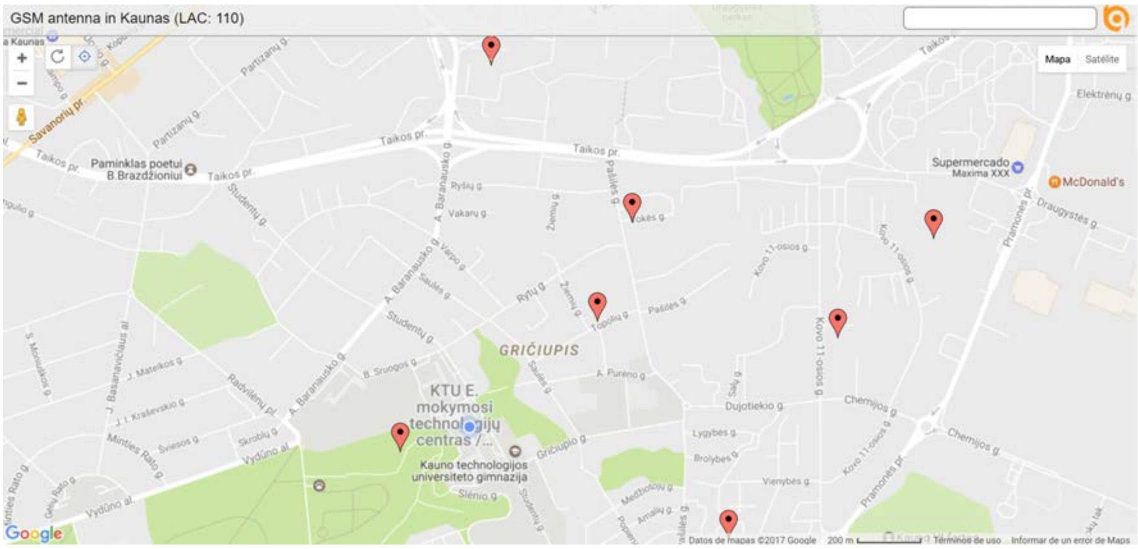


Figure 6.1: Map of GSM antennas received from the laboratory

The area displayed in the map corresponds with a part of the city of Kaunas (Lithuania) which is located next to Kaunas University of Techonlogy, in particular, the Faculty of Electrical and Electronics Engineering (blue point in the map). The laboratory where the present project was developed, has the following coordinates: 54°54'15.3"N 23°57'28.5"E

The following table shows information of the seven most powerful antennas close to the location of laboratory:

MCC	MNC	LAC	CellID	Longitude	Latitude
246	1	110	21132	23.963336	54.907429
246	1	110	23115	23.964955	54.910092
246	1	110	21131	23.969481	54.901554
246	1	110	21035	23.954087	54.903905
246	1	110	21130	23.974598	54.906984
246	1	110	23116	23.958346	54.914314
246	1	110	29051	23.979099	54.909651

Table 6.1: Information of GSM antennas close to the laboratory

As it can be seen in the table 6.1, the Mobile Country Code (MCC) of Lithuania is 246, and the Mobile Network Code of Omnitel (Telia) is 01 (the SIM card used is this project belongs to this company). Both values are used to uniquely identify a mobile network operator (country and company) using the GSM, UMTS, and LTE public land mobile networks.

The third column is the Location Area Code (LAC), which is the reference for identify location areas of cellular radio networks. The fourth column is the Cell ID, which is an unique reference for each antenna in each location area.

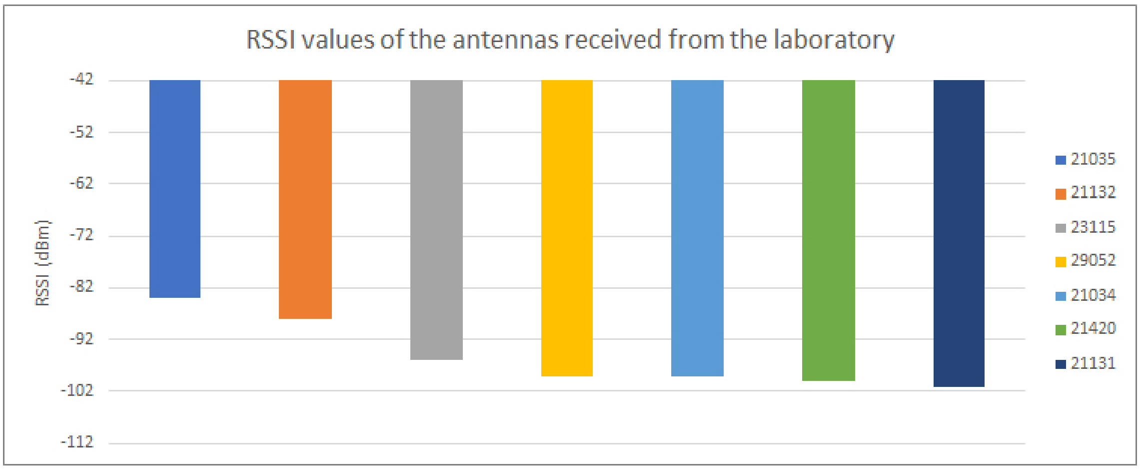


Figure 6.2: RSSI values of the antennas received from the laboratory

As can be seen in figure 6.2, antennas 21132 and 21035 were the most powerful antennas in the area next to the lab and, thereby they were the selected antennas for the analysis.

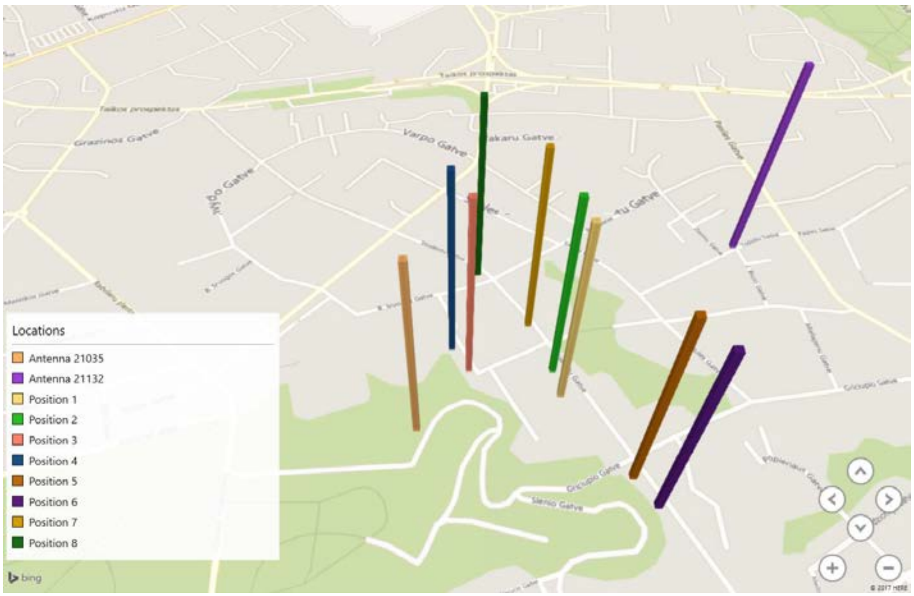


Figure 6.3: Location of antennas 1 and 2, and the measurement points

Figure 6.3 represents position of the two antennas chosen for the analysis and the eight points where the drone lifted up measuring the RSSI. Concerning measurement positions, the criteria was to choose them in separate points, quite far from buildings, cars and trees but also close to the antennas. The university and its surroundings are crowded areas, so it was necessary to be really careful executing the experiments.

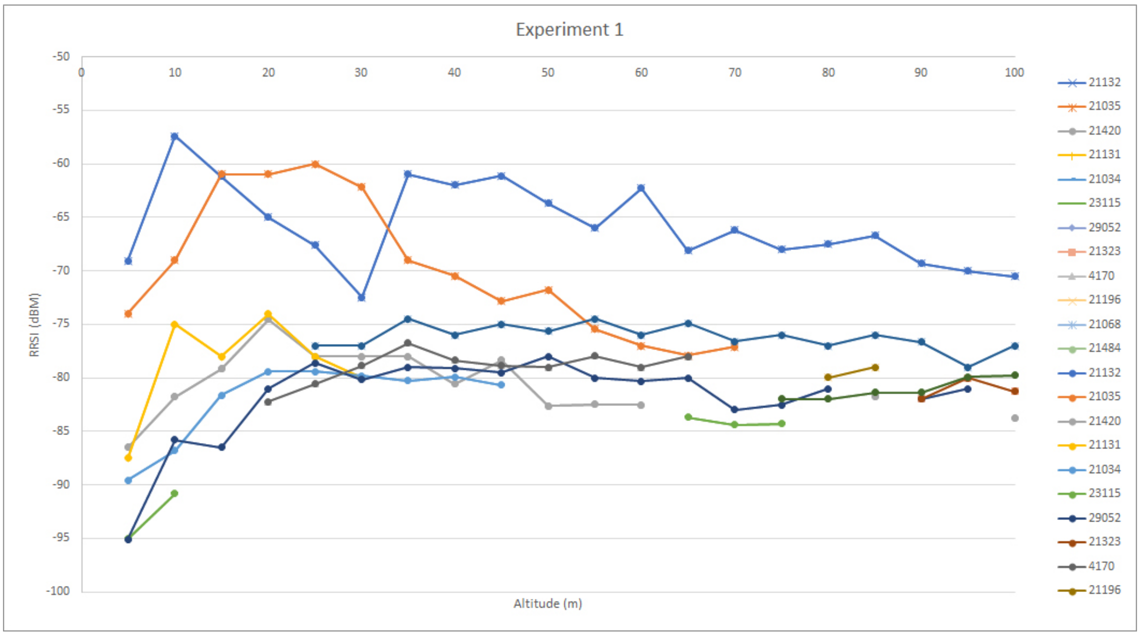


Figure 6.4: First experiment

Figure 6.4 represents all the RSSI values received from the different antennas in the first flight lifting up to 100 meters. It is possible to see that the values are fluctuating as it rises in height.

6.2 Information obtained of Antenna 1 and 2

Figure 6.5 represents RSSI values obtained from antenna 21132 in the different measurement points from 10 to 100 meters.

There many differences in the values at low altitudes. The reason is abortion and reflection of the signal because of buildings, cars, trees, traffic signs, etc.

At medium and high altitudes, it is possible to see a certain tendency in the signals from different positions. The measurements points that are closer to the antenna have best values of RSSI. Therefore, it makes sense.

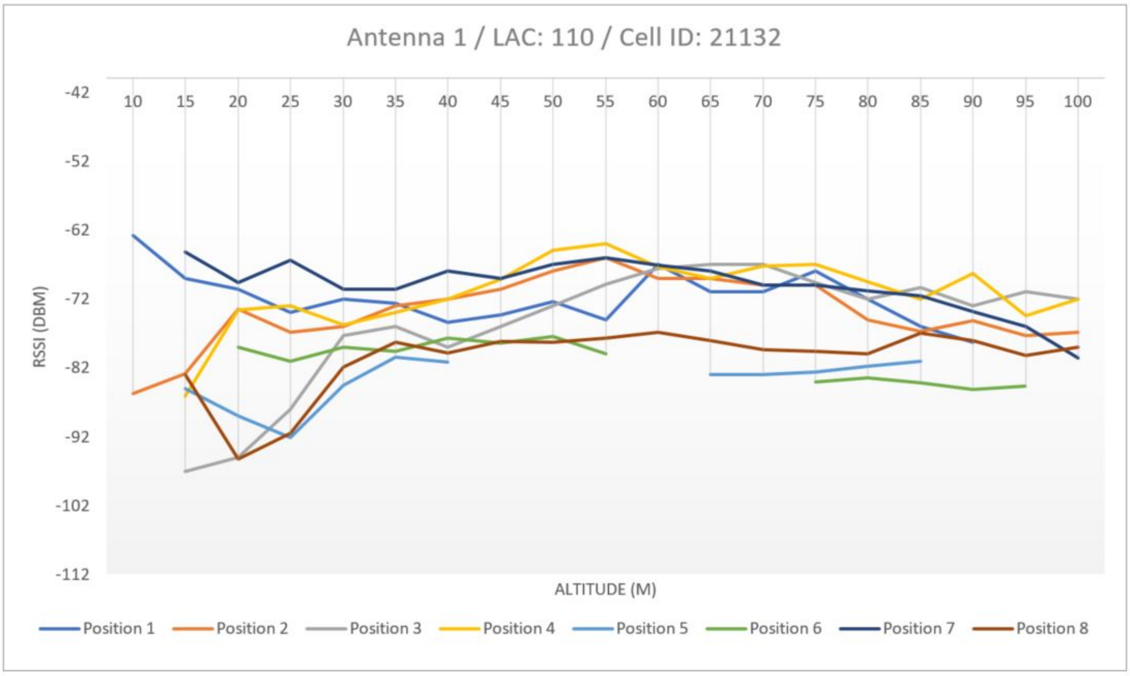


Figure 6.5: RSSI values of antenna 1 from different altitudes and positions

Figure 6.6 represents RSSI values obtained from antenna 21305 in the same measurements points.

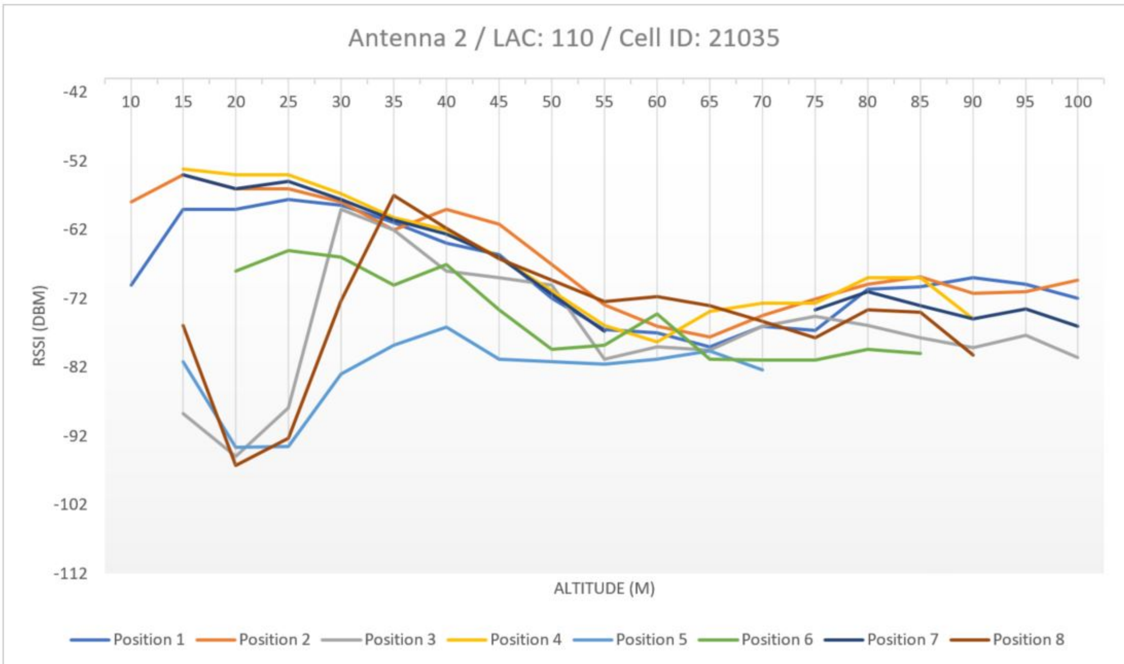


Figure 6.6: RSSI values of antenna 2 from different altitudes and positions

In figures 6.7 and 6.8, it is possible average values for both antennas. For the antenna 1, position 7 is the point with the highest average value of RSSI and position 5 is the worst one. For the antenna 2, position 2 is the best one and position 5 again the worst one.

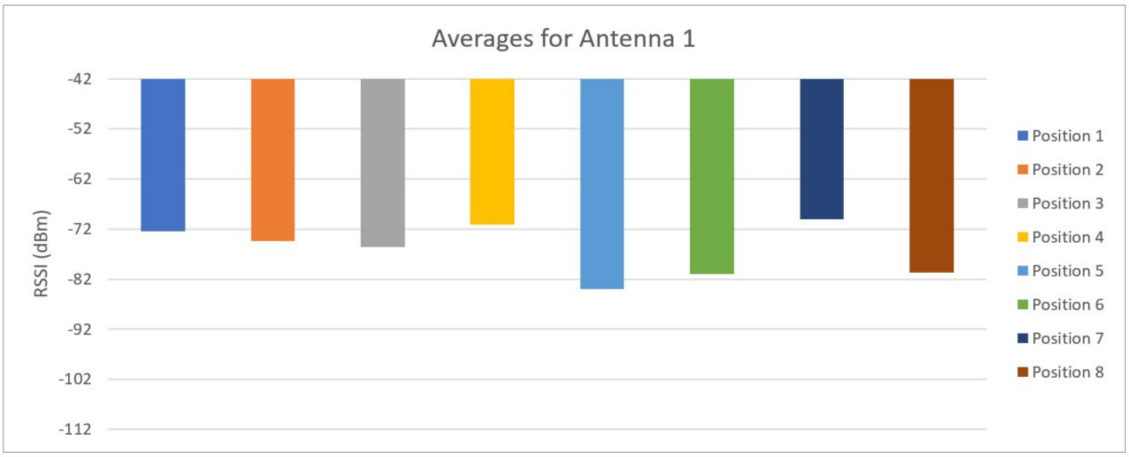


Figure 6.7: Average values for antenna 1

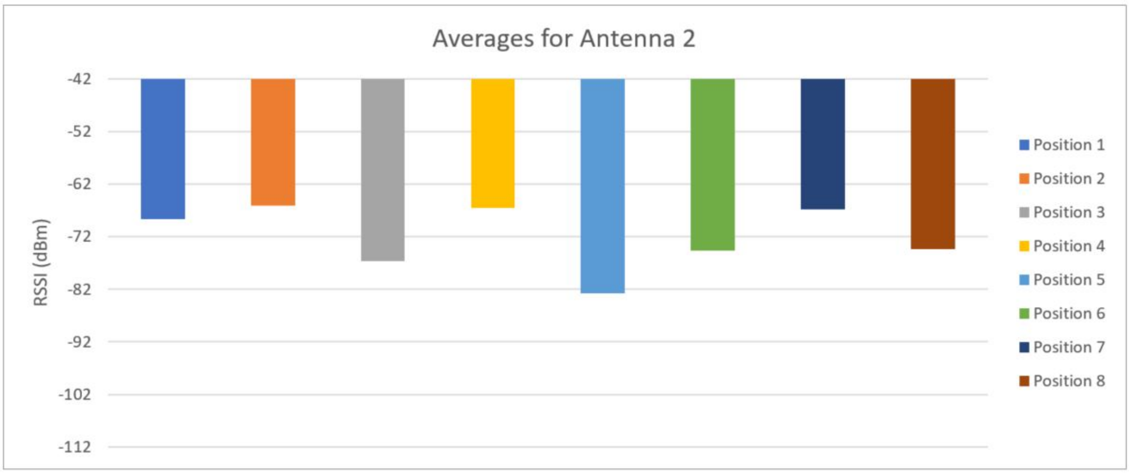


Figure 6.8: Average values for antenna 2

6.3 RSSI Values from different positions

In the following pages it is possible to see the maximum, minimum and average values of all antennas from different altitudes in the different measurement points.

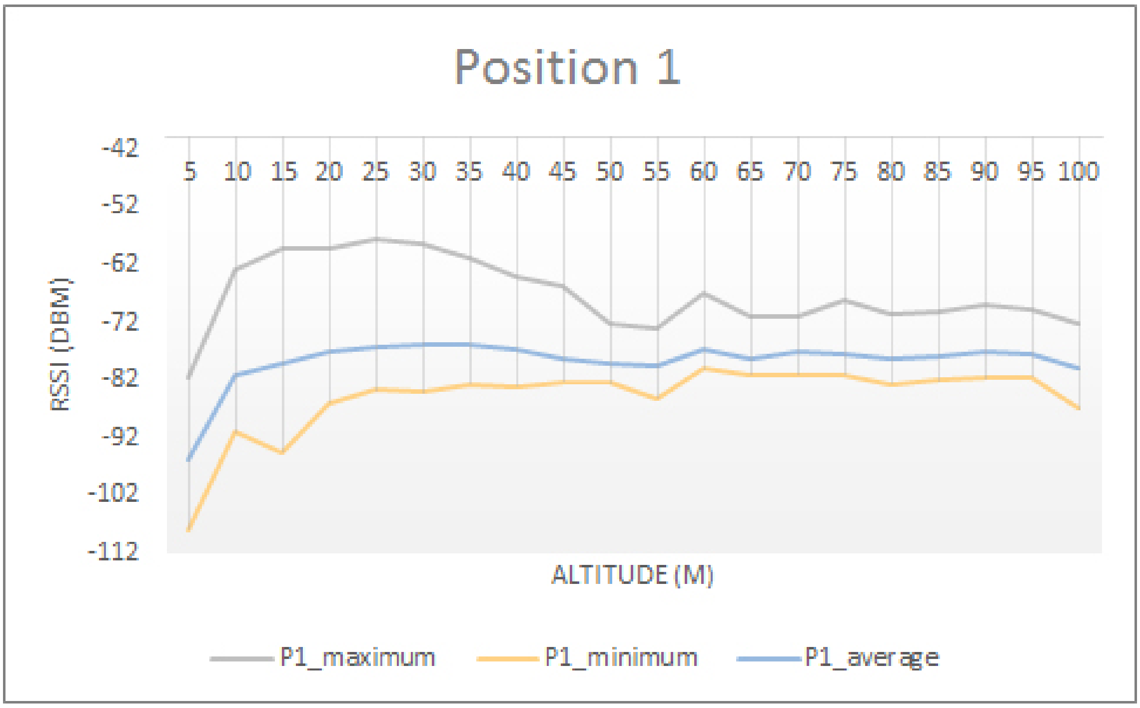


Figure 6.9: Max, min and avg values from different altitudes in position 1

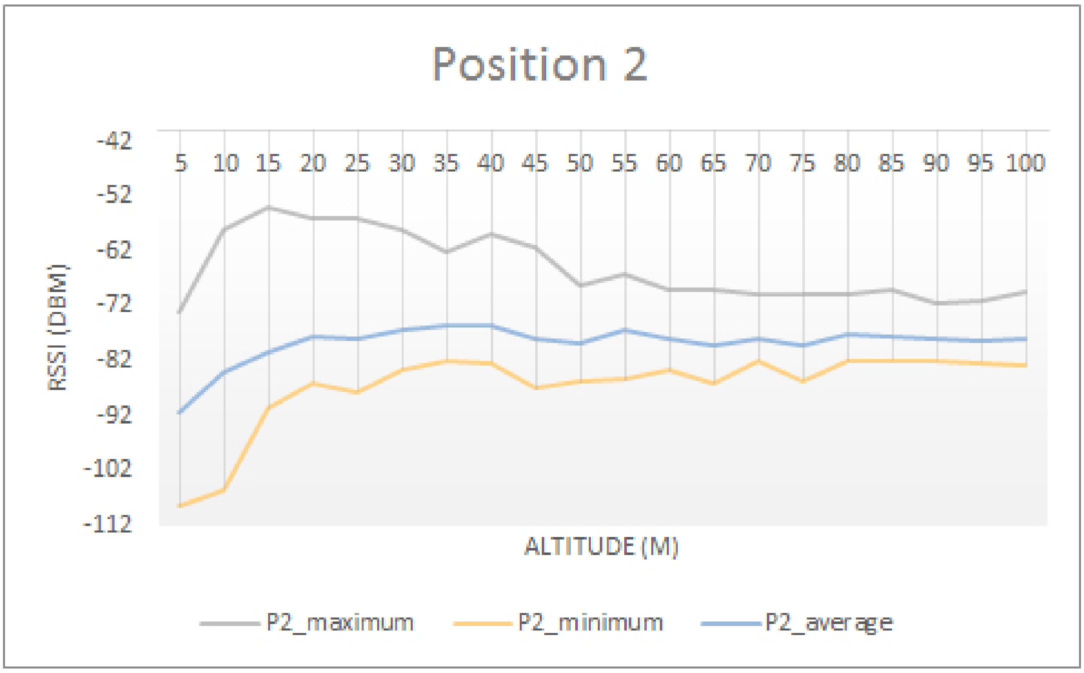


Figure 6.10: Max, min and avg values from different altitudes in position 2

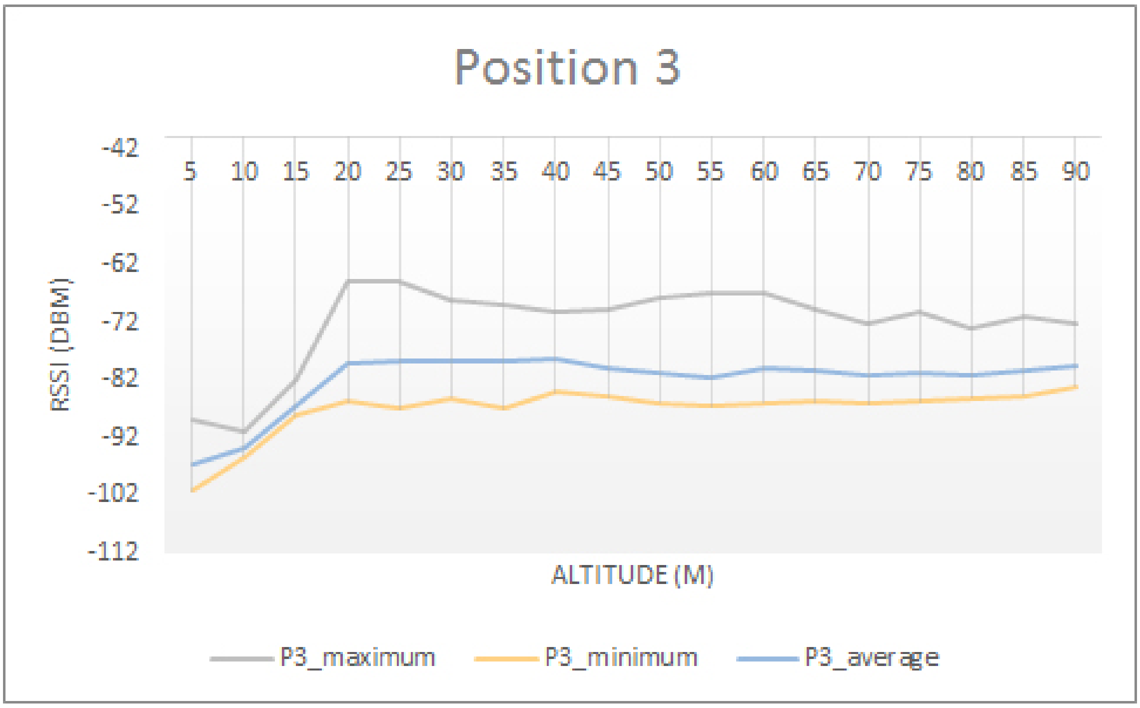


Figure 6.11: Max, min and avg values from different altitudes in position 3

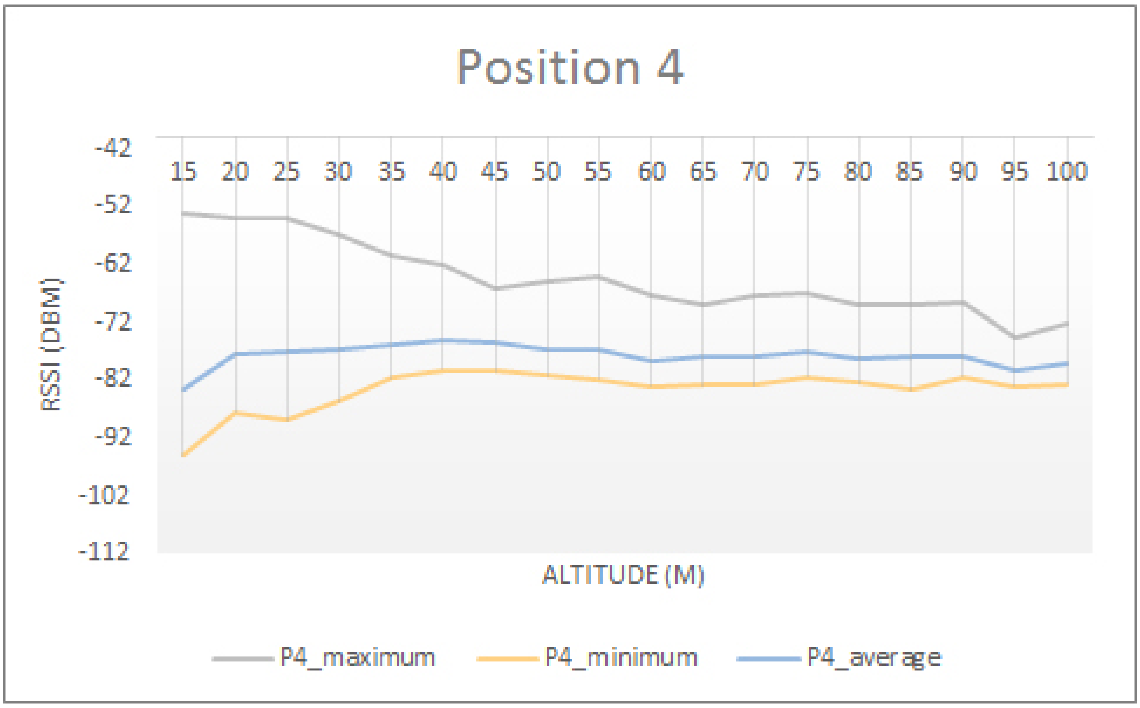


Figure 6.12: Max, min and avg values from different altitudes in position 4

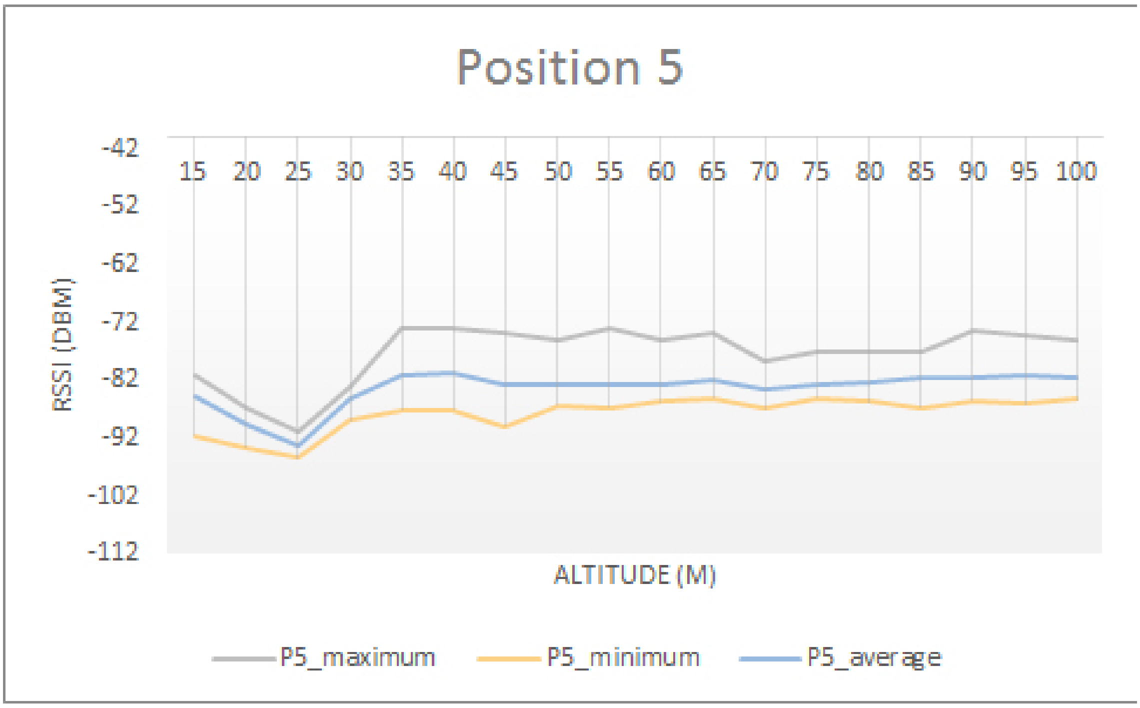


Figure 6.13: Max, min and avg values from different altitudes in position 5

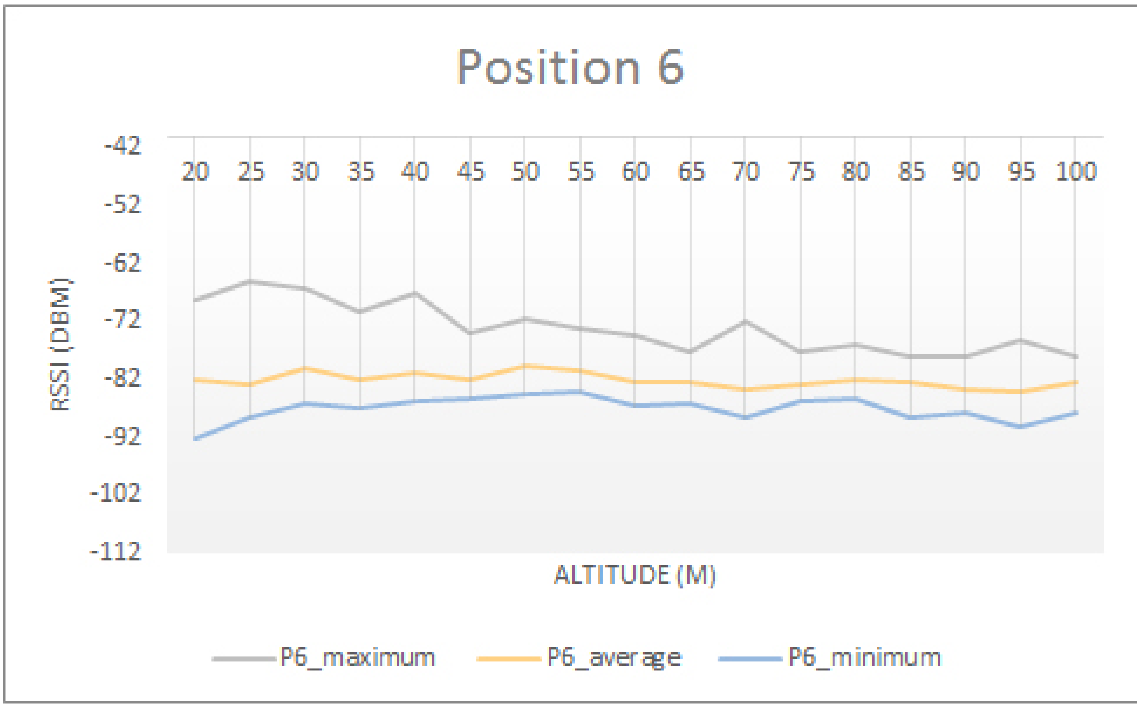


Figure 6.14: Max, min and avg values from different altitudes in position 6

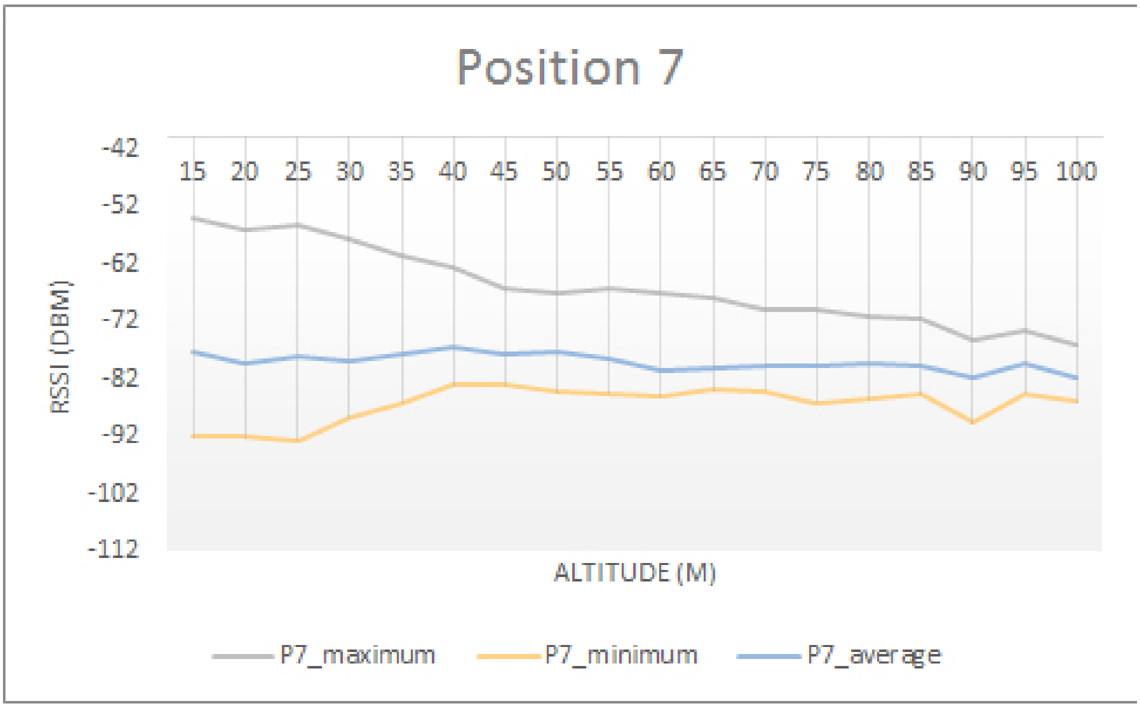


Figure 6.15: Max, min and avg values from different altitudes in position 7

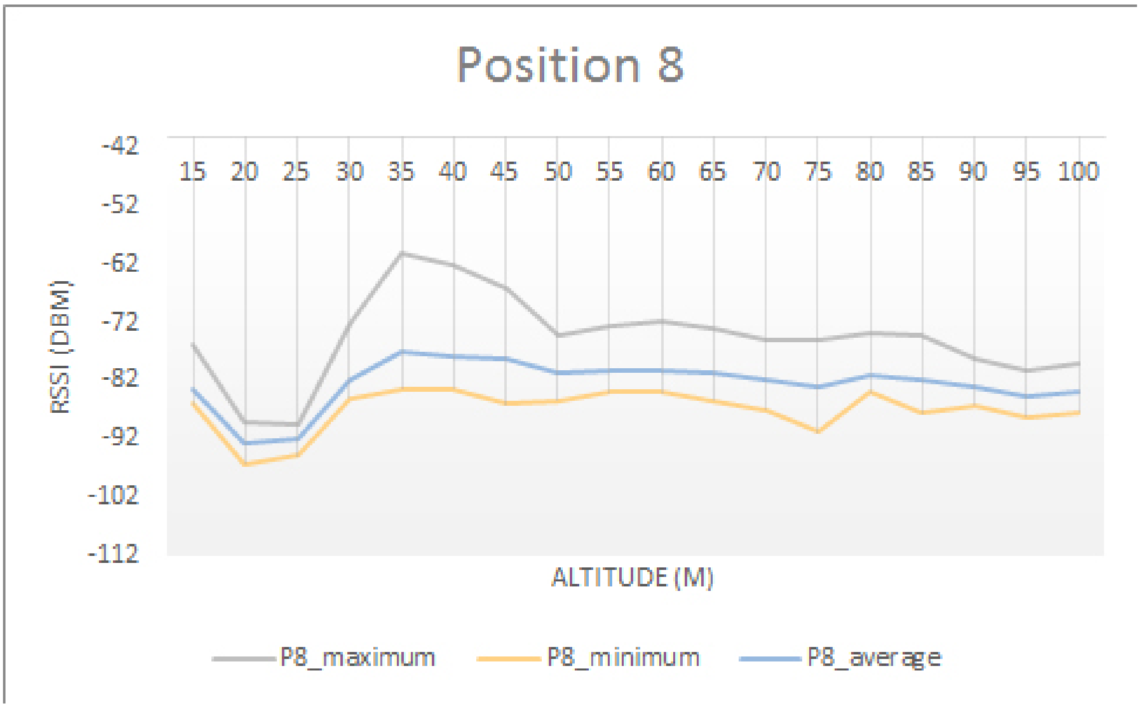
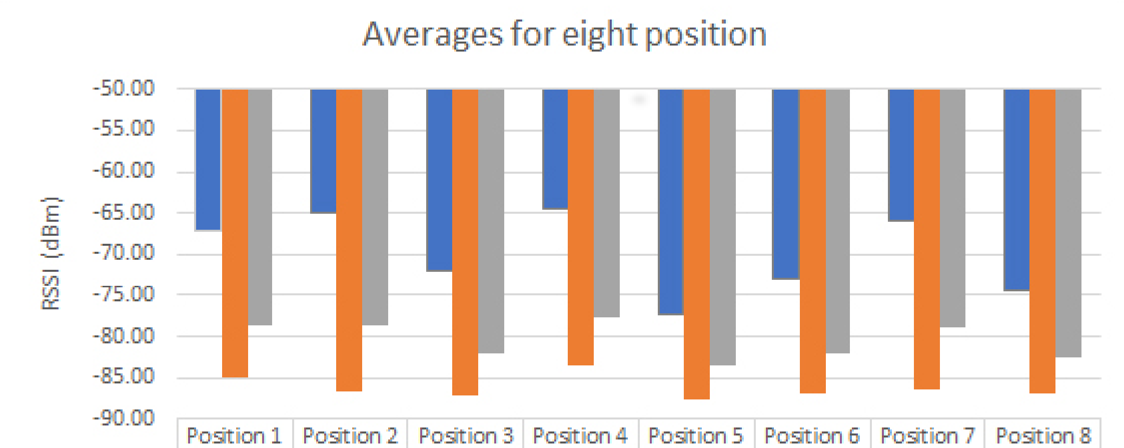


Figure 6.16: Max, min and avg values from different altitudes in position 8

Figure 6.17 represents a summary of last eight graphics with average values for all the positions.



	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Position 7	Position 8
Maximum	-67.14	-64.98	-72.11	-64.36	-77.26	-72.91	-65.94	-74.51
Minimum	-84.99	-86.62	-87.02	-83.59	-87.69	-86.94	-86.35	-86.92
Average	-78.76	-78.74	-81.99	-77.73	-83.47	-82.00	-78.93	-82.44

Figure 6.17: Averages values for all the positions

6.4 GSM signal strength maps

Finally, this section includes some heat maps of the GSM signal strength average for both antennas. Note that these maps only cover one small part of the area. The area that is not painted was not object of analysis.

Probably only eight positions are not enough to make a good and accurate heat map. However, this section is a proof of concept that the developed system could be used to elaborate this kind of maps.

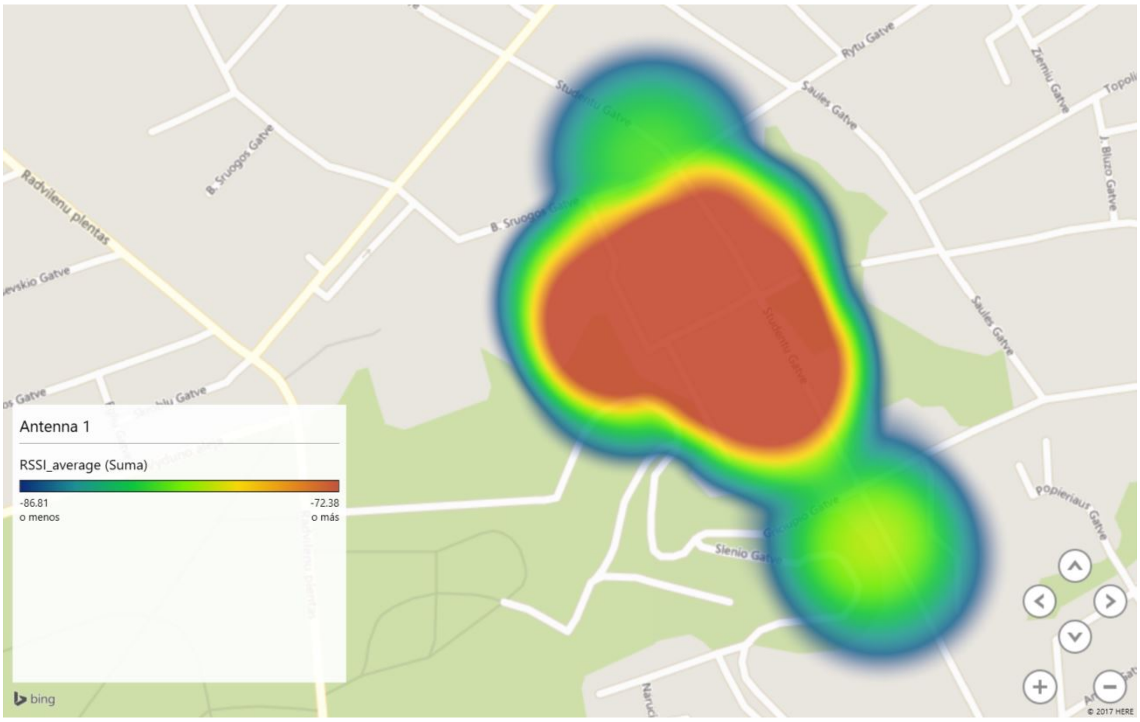


Figure 6.18: GSM signal strength map for antenna 1

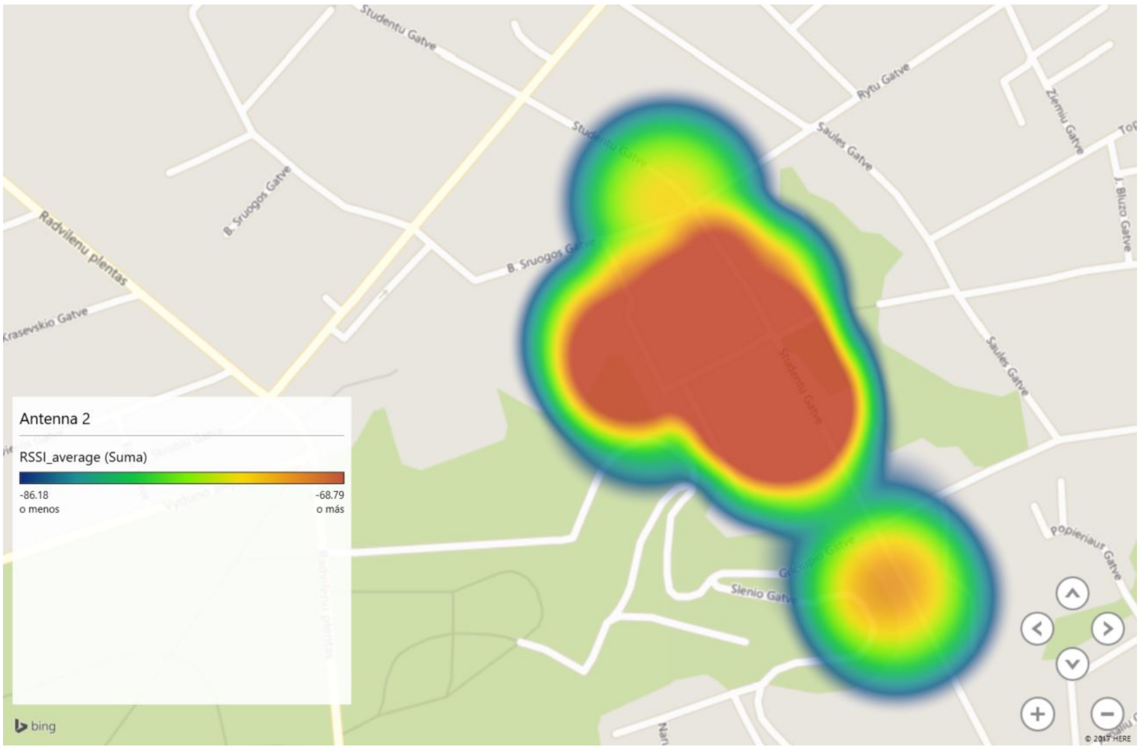


Figure 6.19: GSM signal strength map for antenna 2

Chapter 7

Conclusions

The purpose of this bachelor's final project was to research whether a drone based measurement system for radio frequency is a feasible concept.

Results showed that a drone based measurement system is both a feasible and a working concept. Using this system makes it possible to reduce costs and manual labour of traditional way of measurements, to get accurate and timely measurement data.

This project is only the beginning and a brief introduction to measurement systems based on drones. The field of work is very broad. Any kind of sensor, such as pollution or temperature sensors, could be installed on the drone because of the modularity and flexibility of the developed system.

The development of this project shows the importance and benefits of integrated systems. The integration of drones and other subsystems creates numerous company use cases and a promising future. In this project, a drone, a single-board computer and a GSM signal strength measurement system were integrated into one system. Thanks to the developed software and algorithms, they work as a whole.

This project also shows the complexities of GSM signal strength measurements at low altitudes. Nowadays, cities are crowded areas, full of people, cars, building and vegetation. All these elements produce many interferences, reflections and absorptions of GSM and other RF signals. However, it is easier to measure the GSM signal strength at medium and high altitudes.

After creating the system, one can see the need of drone-open architectures for integrated systems. The truth is that not all the software code can be open source and there must be some minimum safety rules and procedures. However, drone-assembling companies must realize the potential of the integration of drones in other systems, and therefore the business opportunities that it generates. DJI is a good example, since they have created a developers section in their website and they have released an SDK (software development kit) that allows developers to the create applications for DJI drones.

Regarding measurements of GSM signals, the GSM module chosen is possibly not the best measuring device. Precision and accuracy of the data obtained during the experiments showed that it is not the best solution. The ten seconds of delay in the GSM module could be an obstacle since the batteries last for a short time. However, one of features of this project is the price. This project is a demonstration of a concept intended to showcase that, thanks to the advancements in technology, open-source and open-hardware architectures, this kind of projects are possible with an affordable budget.

It is important to talk about Software Defined Radio (SDR), which is a radio communication system where components that have been typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system. A possible future development would be to use this system in instead of the GSM module. In addition to measure GSM signals, it would be possible to improve the reliability and accuracy of the experiments and to measure any radio frequency signal since this system's bandwidth is totally reprogrammable.

Concerning the result of the experiments, it is possible to say that the area is well covered by GSM signals. If you analyse the data and average values for the different positions, you can see that there are only some insignificant fluctuations.

Another problem that I had during the development of the project was not having a physical screen to see the log data on the field during the experiments. Developing an Android app and using the protocol called "Data Transparent Transmission" developed by DJI for this purpose could be a good solution. The system is only flying in a vertical mode. The solution would be to implement horizontal flights with an object avoidance system. An object avoidance system with ultrasonic technology has already been developed. However, the scope of this kind of system is small. Developing obstacle avoidance with some cameras and image processing techniques would expand the boundaries of the system developed.

As it was said before, the developed software is open-source and available for everyone. Therefore, future students of Kaunas University of Technology or any other could continue researching and improving the results obtained in this project.

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