Universidade de Coimbra

Faculdade de Ciências e Tecnologia

Departamento de Física

Portable System for Vital Signs Measurement - Firmware

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I would like to thanks to the professor Carlos Correia and professor José Basílio Simões. They were the responsible by the connection of the students with the persons that could help us.

Resumo

O projecto Sistema Portátil para Medição de Sinais Vitais foi o resultado de uma parceria entre o Departamento de Física da Unversidade de Coimbra e a empresa ISA. O projecto teve a partição dos alunos Emeline Gonçalves, Ricardo Martins e Tiago Marçal e foram orientados, principalmente, pelo professor Carlos Correia, pelo professor José Basílio Simões e o enginheiro Paulo Santos.

Ao longo deste documento é descrita a estratégia seguida para o desenvolvimento do projecto. Inicialmente, o aluno tomou contacto com novos conceitos e novas tecnologias úteis para um posterior desenvolvimento das tarefas solicitadas. A aprendizagem recaiu na aprendizagem de programação em C, o que são microcontroladores e a construcção de projectos de programação para microcontroladores baseados em exemplos. Já depois de finalizada esta apredizagem entendeu-se que também seria útil aprender conceitos sobre a tecnologia de comunicação *wireless* Zigbee.

Após o período inicial de assimilação de conceitos, procedeu-se à formulação de toda a documentação necessária, Visão e Objectivos, Análise de Requisitos e Arquitectura do Sistema, para melhor enquadrar o nosso projecto à realidade actual. Esta documentação, para além da ideia anterior, teve também como objectivo antever todos os processos e passos a seguir, de forma a que não existissem falhas no momento da execução do código.

Por fim, e de forma a testar a montagem das placas dos módulos de aquisição e de transmissão, elaborou-se um código de teste.

Abstract

The project Portable System for Vital Signs Measurement was the result of a partnership between the Department of Physics of the University of Coimbra and the company ISA. The project was composed by three students, Emeline Gonçalves, Ricardo Martins and Tiago Marçal, and three supervisors, professor Carlos Correia, professor José Basílio Simões and engineer Paulo Santos.

Through the document, it is described the strategy followed for the project's development. In the beginning, the student had contact with new concepts and new technologies for the development of the request tasks in the future. The student learned about C programming language, microcontrollers and, with the help of some examples, builds some programming's projects. After finishing this knowledge acquisition, it was decided that he will, also, learn about Zigbee wireless protocol.

When the initial learning finished, it takes place the write of the project's documentation. The documentation includes the Vision and Objectives, Requisites Analysis and the architecture of the project. The idea was to acquire knowledge about the state-of-the-art, the needs of the healthcare provider and prevent all the possibilities when the system is working.

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Chapter 1

1. Introduction

In the last few decades, the medicine has improved the quality of their services. Now, it is possible to heal and, more important, to prevent several diseases who, in the past, were impossible to diagnosis. The evolution of the technology, with the help of the engineering, physics and mathematics, was very important to achieve this level of commitment. Currently, the physicians have a huge and diverse set of techniques to know better the clinical situation of his patient. One of the areas that evolved a lot in the last years was the area of the telehealth care. Telehealth, or telemedicine, is a brand new concept and means the use of medical information exchanged from one site to another via electronic communications to improve patients' health status. With this concept, the healthcare provider is capable to follow the evolution of his patient without a near contact. Using this service, the patient can be in the hospital but, also, at home.

In the present day, the management of the hospitals suffers with the economic restrictions in the budget and, therefore, the hospital will try reducing the expenses. They try increase the efficiency and, often, the ratio, between the healthcare providers and the inpatients, is low. The low ratio can be the result of firing healthcare providers, an increase of inpatients, without employ new healthcare providers, or both. With an overload of work, by the staff, it is possible that the inpatients don't have the best accompaniment. In the worst situation, a critical event, like a stroke or cardiac arrest, can occur with an inpatient and no assistance is taken. With the same objective, the time that a patient is in the hospital is the lowest possible. It is possible that the inpatient is able of leave the hospital but some precautions are necessary, like watching the physiological parameters.

The implementation of a telehealth system will bring benefits to the population and to the healthcare system provider. People living far away from the urban areas have difficulties to access to a quality medical care in time. Residents of these areas don't have, sometimes, access to some medical specialties because the physicians are located, mostly, in urban areas. A telehealth system can be used to approach physician and patient, geographically far away, once the system allows, to the physician, watch the evolution of the patient's status. When it is necessary, the physician calls the patient to the hospital for complementary tests or a consultation routine.

Put together all these situations, discussed in the previous paragraphs, is possible to identify the needs of the healthcare system and what the advantages and the disadvantages of the implementation of such device.

1.1. Objective

The objective of the project is the development of a system that can be used to acquire, transmit and show physiological parameters, vital signs, for the physician or another healthcare provider. The vital signs acquired must be updated to a host computer, where they can be seen and managed. The information will be updated for the host computer in one of two methods. The first method is to use a wire technology to connect, physically, the host computer with the electronic device that has the information. The second method uses a wireless technology to exchange information. The wireless technology is also used to transmit the data between the electronic device that collected the data and a second electronic device that will send the data to the host computer.

The objectives, in a temporal order, are:

1. Knowledge acquisition:
   - 1.1. C programming;
   - 1.2. Microcontrollers;
   - 1.3. Zigbee.
2. Documentation:
   - 2.1. Vision and Objectives;
   - 2.2. Requirements Analysis;
   - 2.3. Data Center Skin;
   - 2.4. Communication Protocols;
   - 2.5. Flowcharts.
3. Zigbee Study:
   - 3.1. Documents;
   - 3.2. Stack.
4. Programming acquisition and transmission modules:
   - 4.1. Test Code;
   - 4.2. Firmware.

1.2. Scope

This project is the result of a partnership between the company ISA and the Department of Physics, and it is inserted in the Project course of Biomedical Engineering 5th year and the duration of the Project course is all the academic year 2006/2007. During this time, the professor Carlos Correia was the responsible by the supervising at the Department of Physics. Professor José Basílio Simões and the engineer Paulo Santos were the responsible by the supervising at the ISA.

1.3. Audience

This document has, as main target, the jury, assigned for the defense, and the supervisors of the Department of Physics and ISA. The document describes the evolution of the project along the academic year 2006/2007. He reports the knowledge acquisition phase and the documentation developed.

1.4. Document's structure

The document is divided in chapters. Each chapter represents a block, with different subjects spoken, of work developed through the academic year. The:

- First chapter is used to present the problem, why a project like this, and define the main target of the document;
- Second chapter presents the project's team, students and supervisors, the scheduling and the Grant Diagram with the developed tasks;
- Third chapter report the different concepts and technologies studied;
- Fourth chapter allows know better the different systems already in use;
- Fifth chapter analyses physiological parameters and dataflow. With the properly knowledge, it will be easiest build a good solution;
- Sixth chapter is important because it is here that will be discussed the Data Center Skin, the Communication Protocols and the Flowcharts;
- Seventh chapter is the conclusion. Here, the student resumes the work made and he talk about the non conclusion of the project.

Chapter 2

2. Project Planning and Management

2.1. Project's Team

The project had 3 students and 3 supervisors. Although the students have made some works together, each student had different tasks to do. The supervisors had the responsibility of manage all the process.

Name	Function	Contact
Emeline Gonçalves	Student	emeline.alves@gmail.com
Ricardo Martins	Student	ricardomartins112@gmail.com
Tiago Marçal	Student	silvamarcal@gmail.com
Professor Carlos Correia	Supervising	correia@lei.fis.uc.pt
Professor José Basílio Simões	Supervising	jbasilio@isa.pt
Engineer Paulo Santos	Supervising	psantos@isa.pt

Table 1: Project's Team.

2.2. Supervising at ISA

With a strong knowhow in the area of the telemetry, the company ISA was very important to outline a good strategy in the development of all system. Several meetings have occurred at the ISA between students, supervisors and others ISA's collaborators. Like the meetings at the CEI, here, these meetings were used to discuss ideas and what the best solutions to the project.

In the end of the academic year, the students have gone to the ISA because, at this time, the tasks that they have had to do justified the close contact with persons that could help.

2.3. Supervising at CEI

The Electronic and Instrumentation Center, CEI, was the bridge between the University and the company ISA. Professor Carlos Correia was the supervisor in the CEI and the person that help the students in some doubts. Here, the students had some meetings with the professor Carlos Correia and, sometimes, with an ISA's collaborator to discuss the best solutions to the project.

The students have passed most of the academic year at CEI and, with the objective of improve the study, CEI bought some material and another, that it exists, was placed to the disposal.

2.4. Tasks Division

Over the academic year, the students have had tasks in common, like write the documentation, and individual tasks, like programming the hardware. Between the individual tasks, the students work together to create all the documentation necessary to the project. This documentation includes the state-of-the-art and communication protocols. After the documentation to be finished, each student has dedicated his time to the individual tasks. The individual tasks made by me are:

- Study C programming;
- Study Microcontrollers;
- Study Zigbee;
- Flowcharts;
- Test Code.

When Emeline got in for this project, it was necessary a tasks' redistribution between the students. In this new format, Emeline became responsible by the Acquisition Module, I became responsible by the Transmission Module and the Data Center was attributed to Ricardo. Before this, Ricardo was the responsible by the hardware, for the Acquisition and Transmission Modules, and I was responsible by the firmware, for the same modules. Now, a new concept was adopted. Each student was responsible for an entire module. In the case of the Acquisition and Transmission Modules, the student would develop both firmware and hardware. In the case of the Data Center, the student would develop the software to run in a host computer.

However, this distribution wasn't good because, in the case of the Acquisition and Transmission Modules, the students would learn the same but much more time would be necessary. After some meetings between the students and the supervisors was decided to split the work in logical blocks. Emeline became responsible by all hardware and I became responsible by all firmware for both, Acquisition and Transmission, modules. Ricardo kept his work.

2.5. Scheduling

At the beginning of the academic year the individual tasks were split by the two students of the project:

- Ricardo was responsible by the development and implementation of the hardware. This hardware will be the prototype for the Acquisition and Transmission Modules;
- I was responsible by the firmware. This type of software will be implemented in the Acquisition and Transmission Modules to do several tasks, like acquire analogue and digital data (the physiological parameters), and to send the data through the different modules until arrive to the Data Center.

In the end, the project was split in three main tasks. Each task was attributed to a student. The three tasks are:

- Design and build an hardware prototype to the Acquisition an Transmission Modules;
- Create an embedded software, a firmware, to run in the Acquisition and Transmission Modules;

- Develop the software to the Data Center. This software will permit to the healthcare provider watch the evolution of the clinical status of the patients.

However, the scheduling of the project did not have a rigid structure. The scheduling was flexible and, always when necessary, it was changed. The work developed by the student over the academic year can be seen in the figure 1, 2 and 3.

ID	Task Name	Start	Finish	Duration
1	**Vital Signs – 1st Semester**	11-09-2006	26-01-2007	20w
2	**CEI Integration and the first meetings**	11-09-2006	15-09-2006	1w
3	**Identify some needs – Know Centro Cirúrgico de Coimbra**	18-09-2006	29-09-2006	2w
4	**Acquisition of Knowledge**	02-10-2006	13-12-2006	10w 3d
5	C programming	02-10-2006	01-11-2006	4w 3d
6	Microcontrollers - Theory	02-11-2006	30-11-2006	4w 1d
7	Microcontrollers - LED	01-12-2006	13-12-2006	1w 4d
8	**School Pause - Exams**	14-12-2006	26-01-2007	6w 2d

Figure 1: Scheduling of the first semester.

ID	Task Name	Start	Finish	Duration
1	**Vital Signs – 2nd Semester (1st Part)**	29-01-2007	13-04-2007	11w
2	**Project's Documentation – 1st Part**	29-01-2007	12-02-2007	2w 1d
3	Vision and Objectives	29-01-2007	06-02-2007	1w 2d
4	Requirements Analysis – 1st Version	07-02-2007	12-02-2007	4d
5	**PIC Programming Learning – 1st part**	13-02-2007	16-02-2007	4d
6	EUSART Module	13-02-2007	16-02-2007	4d
7	**First Presentation**	19-02-2007	23-02-2007	1w
8	Preparation to the presentation	19-02-2007	22-02-2007	4d
9	Presentation	23-02-2007	23-02-2007	1d
10	**Project's Documentation – 2nd Part**	26-02-2007	28-02-2007	3d
11	Requirements Analysis – 2nd Version	26-02-2007	28-02-2007	3d
12	**PIC Programming Learning – 2nd part**	01-03-2007	09-03-2007	1w 2d
13	Study of Programming Examples	01-03-2007	09-03-2007	1w 2d
14	**Hardware components search**	12-03-2007	16-03-2007	1w
15	**PICDEM Zigbee Demonstration Board – 1st part**	19-03-2007	13-04-2007	4w
16	Pdf reading about the Zigbee Demonstration board	19-03-2007	20-03-2007	2d
17	Search of Zigbee and WiFi chips	21-03-2007	23-03-2007	3d
18	First discussion about transmission and acquisition module's architecture	26-03-2007	30-03-2007	1w
19	Study of the Microchip Zigbee stack	02-04-2007	13-04-2007	2w

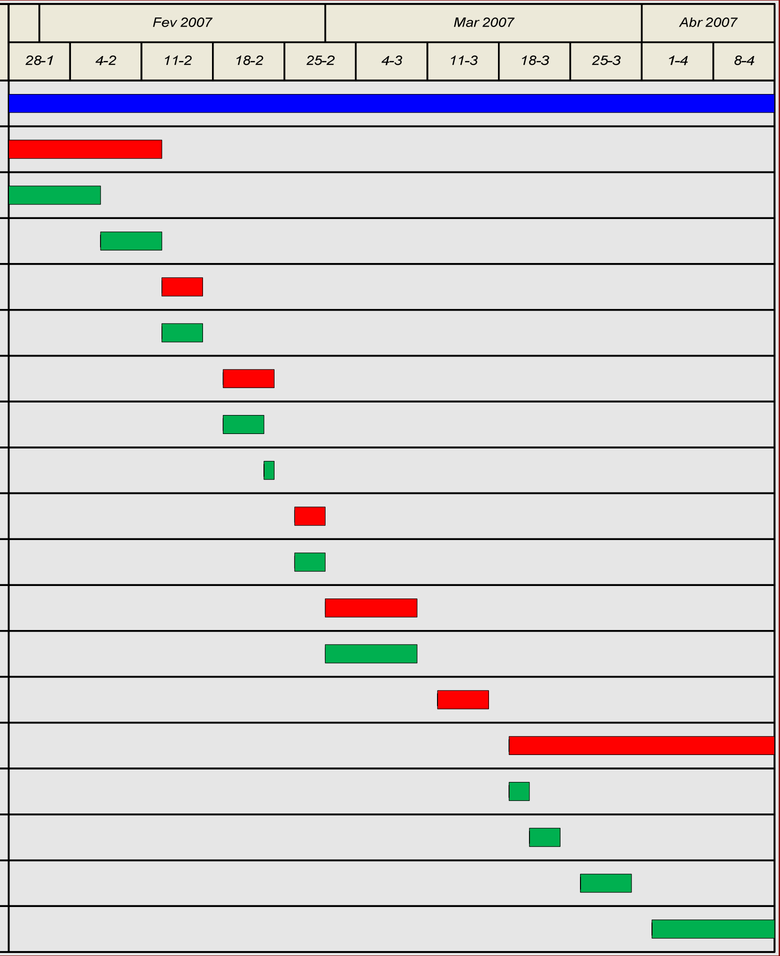

Figure 2: Scheduling of the second semester – first part.

ID	Task Name	Start	Finish	Duration
1	**Vital Signs – 2nd Semester (2nd Part)**	16-04-2007	07-09-2007	21w
2	**PIC Programming Learning – 3rd part**	16-04-2007	21-05-2007	5w 1d
3	SPI Module	16-04-2007	27-04-2007	2w
4	Interruptions	30-04-2007	09-05-2007	1w 3d
5	Timers Module	10-05-2007	18-05-2007	1w 2d
6	Attempt to make delay functions	21-05-2007	21-05-2007	1d
7	**PICDEM Zigbee Demonstration Board – 2nd Part**	23-05-2007	29-05-2007	1w
8	Search the code to send own data between the boards	23-05-2007	25-05-2007	3d
9	Attempt to read a device with SPI interface and send the information to the other board	28-05-2007	29-05-2007	2d
10	**Second Apresentation**	30-05-2007	01-06-2007	3d
11	Preparation to the presentation	30-05-2007	31-05-2007	2d
12	Presentation	01-06-2007	01-06-2007	1d
13	**Architecture**	04-06-2007	18-07-2007	6w 3d
14	Data Center Skin	04-06-2007	15-06-2007	2w
15	Communication Protocols	18-06-2007	29-06-2007	2w
16	Flowcharts	02-07-2007	18-07-2007	2w 3d
17	**Test Code**	19-07-2007	02-08-2007	2w 1d
18	**Write Project's Thesis**	06-08-2007	07-09-2007	5w

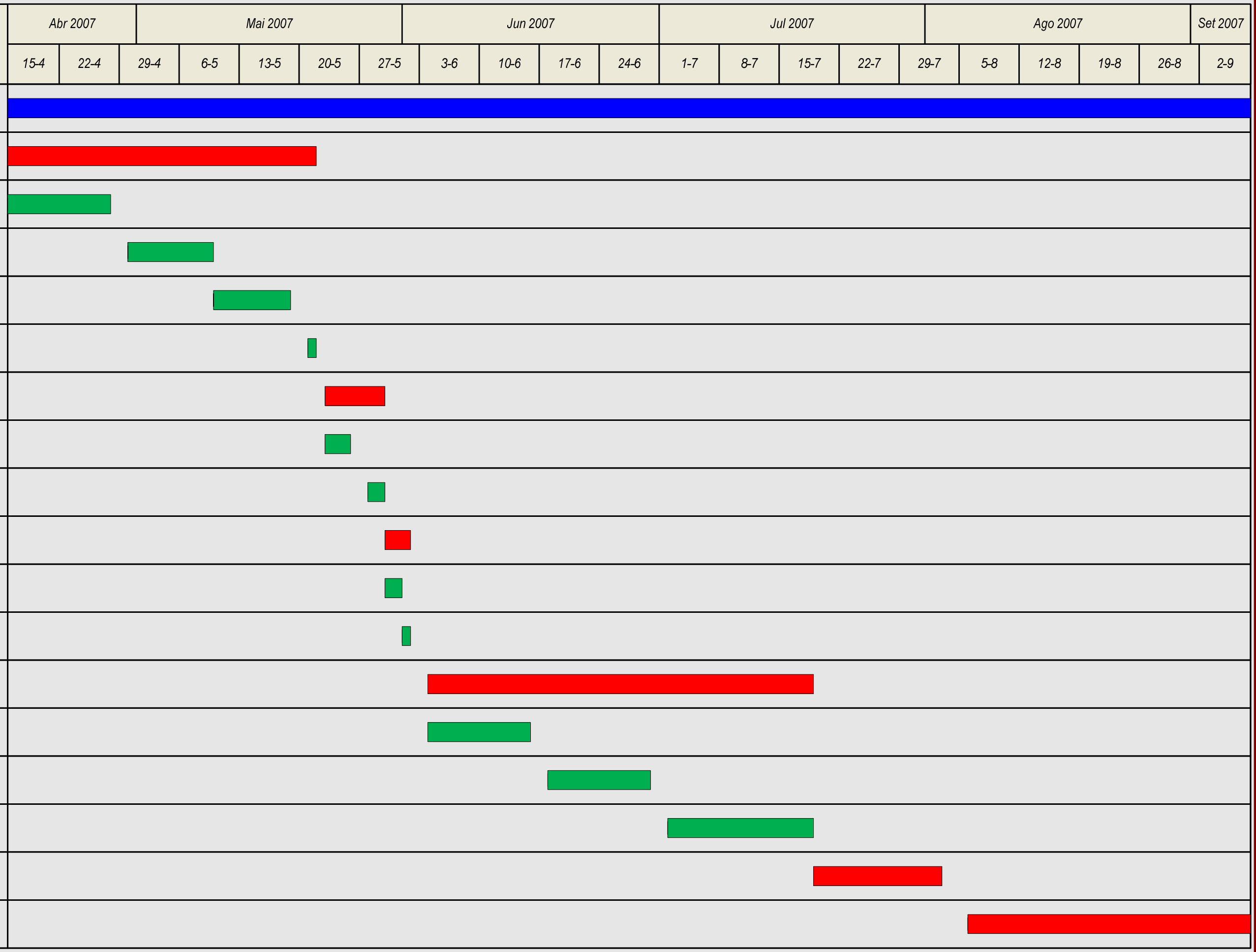

Figure 3: Scheduling of the second semester – second part.

Chapter 3
3. Knowledge Acquisition

The first step for the project was the study of some useful concepts, about programming, and technologies. These concepts will be the basis to the development of both, acquisition and transmission, module's firmware. The study includes c programming, microcontrollers, IDE, and the Zigbee Stack. A good understanding of these concepts and technologies is critical for a good evolution of the project along this year, that is, the quality of the documentation and of the programming will depend of the knowhow.

3.1. C Programming

The C programming language is a low level programming language, widely used for various reasons:

- Extensive use of functions calls;
- Structure Language;
- Pointer Implementation.

This programming language is widely used around the world because it gives maximum control and efficiency to the programmers. The C programming language will allow, to the programmer, read and write code for a large number of platforms, since microcontrollers to the most advanced scientific systems, can be written including several operating systems used in the present day.

C is a compiled language. This means that once the code in write, it must be run through a c compiler to turn the program into an executable that the computer can run (execute). The C programs are human-readable form, while the executable that comes out of the compiler is the machine-readable and executable form.

Another aspect of C that is worth mentioning is that it is a bit dangerous. C doesn't, in general, try hard to protect a programmer from mistakes. If a programmer writes a piece of code which will do something widely different from what programmer intended it to do, up to and including deleting data and if is possible for the compiler it generally. No warning message will offer.

3.2. Microcontroller

The microcontroller is a computer-on-a-chip, a single-chip computer. Such term means that an entire computer system lies within the confines of the integrated circuit chip. The microcontroller contains a CPU, RAM, ROM, I/O lines, serial ports, timers, and, sometimes, other sensor built-in peripherals such as an ADC or a DAC. The most important feature of the microcontroller is the capacity to store and to run a program.

The application of a microcontroller, in embedded systems, is critical because the microcontroller will function as a brain in the human body. In this “brain”, the firmware will run and take decisions based on predetermined situations and selections. Next, it will be discussed some of the different constituents of a microcontroller:

3.2.1. Memory Unit

This part of the microcontroller has as function store data. The memory is split in several blocks. In this way, it is possible to have full control over the access to the memory.

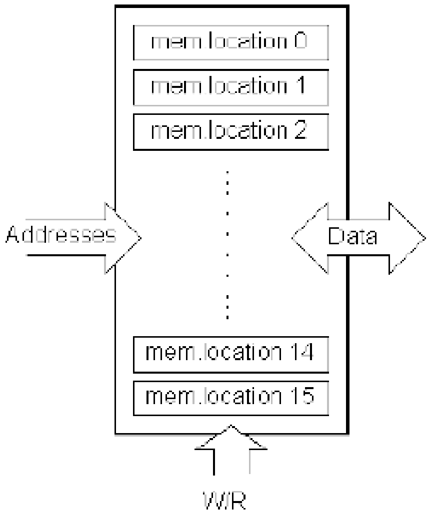

Figure 4: Example of a memory and how she works. (Matic, 2000)

To a better identification and understand of the memory unit, two concepts are used. The first concept is the memory location, the blocks of the memory unit, and the second concept is addressing, the way to access to the memory locations. The memory, to be useful, must allow his reading and his writing. Therefore, a line command exists to allow changes between a read and a write operation.

3.2.2. CPU

The CPU, or central processing unit, of the microcontroller is dedicated to functions like multiply, divide, subtract and move its contents from one memory location onto another. Inside the CPU, there are memory locations. Here, the memory locations are to know as registers. These registers have the function of help the system, performing the mathematical operations or any other operation with data.

3.2.3. Bus

The microcontroller has several blocks. Each block has a task, different from the others. The microcontroller, to perform his tasks, must have the blocks in communication. Therefore, it is necessary link these blocks. To do this job, the microcontroller uses several wires call bus. There are two types of buses. One type is an address type and the other is a data type. The address type serves to transmit addresses from the CPU memory, and the data type connects all blocks inside de microcontroller.

3.2.4. I/O ports

The microcontroller is a powerful device but, if he is unable to communicate with the outside, then he is useless. To avoid this situation, a new block must exist in the microcontroller, the ports. The ports can be input, output or both.

3.2.5. Serial Communications

The I/O ports allow exchange of data between the microcontroller and the outside world. However, to do this, several numbers of lines are required. As the microcontroller is a small electronic device, the resources are few. To avoid the use of many resources, the microcontroller is build to communicate using serial communications. For a successful exchange of data, the serial communication must follow a protocol. There are some different protocols. Some protocols don´t allow the microcontroller receive and send information at the same time because they use the same line to receive and to transmit.

3.2.6. Timer Unit

Into the firmware, running in the microcontroller, it is very useful to the system to have access to time information. With the timer unit, it is possible to control the accuracy moment to send or get information. This process is possible because the unit read an external crystal. The crystal gives a precise frequency and, with a certain frequency (lower or the same frequency of the crystal), a counter is increment a unit.

3.2.7. ADC

The microcontroller is a digital device, only understand the meaning of “0” and “1”. When it is necessary to know the surround environment, it is necessary to use an ADC to collect analogue signs. The ADC will give a digital reading from an analogue environment.

There are several companies in the market offering vast solutions. With the knowhow of the ISA's employees, the solution chosen was the PIC, the Microchip's microcontroller. The Microchip' microcontroller has RISC architecture. With this architecture, the microcontroller has the data bus split from the address memory bus and, therefore, a greater flow of data is possible. In an older architecture, CISC architecture, these lines aren't split and the flow of data is slower than in the RISC architecture. This feature is an important advantaged to the PICs.

3.3. MPLAB IDE

The MPLAB IDE is a Microchip's software program developed to create software projects to the PIC microcontrollers. With the use of the MPLAB IDE, it is possible have a single integrated "environment" to develop code for embedded microcontrollers. An embedded system is a specialized system dedicated to a specific task or set of tasks, running in a single program.

When a programmer writes a code, the process is not linear because he has to write, test, and modify the program several times until the code is finish. This process is called development cycle. With an IDE system, this process allows an easiest work because all the necessary tools are concentrated here.

For the development of the embedded systems, a compiler must be use. For this project, the MPLAB IDE uses the Hi-Tech picc-18 compiler to compile the C programming files because he has a set of instructions and functions dedicated to the PIC microcontroller used that simplifies the project's development.

3.4. Zigbee

The wireless technologies have more and more importance in the present day. There are many types of equipment in function with the support of the wireless technologies, as example, the cellular phones, the PDAs, the GPS and the PC. However, there is more than one wireless technology. Zigbee, a wireless network protocol, is one of the existing wireless technologies, and he is designed for low-rate wireless personal area networks.

The Zigbee stack architecture has several blocks called layers. This type of architecture has, as main objective, give to the layers different services. In each service there is an interface to the upper layer through a service access point. The two lower layers are the physical, PHY, and the medium access control, MAC, layers of the IEEE 802.15.4 standard. After these two layers, the Zigbee Alliance implements more layers: network, NWK, application support sublayer, APS, and zigbee device object, ZDO (see figure 5). After these layers, there is a layer, the application layer (APL), where the programmer can put his programs.

The Zigbee protocol allows the use of three frequency bands of operation:

- ≈868MHz;
- ≈915MHz;
- ≈2.4GHz.

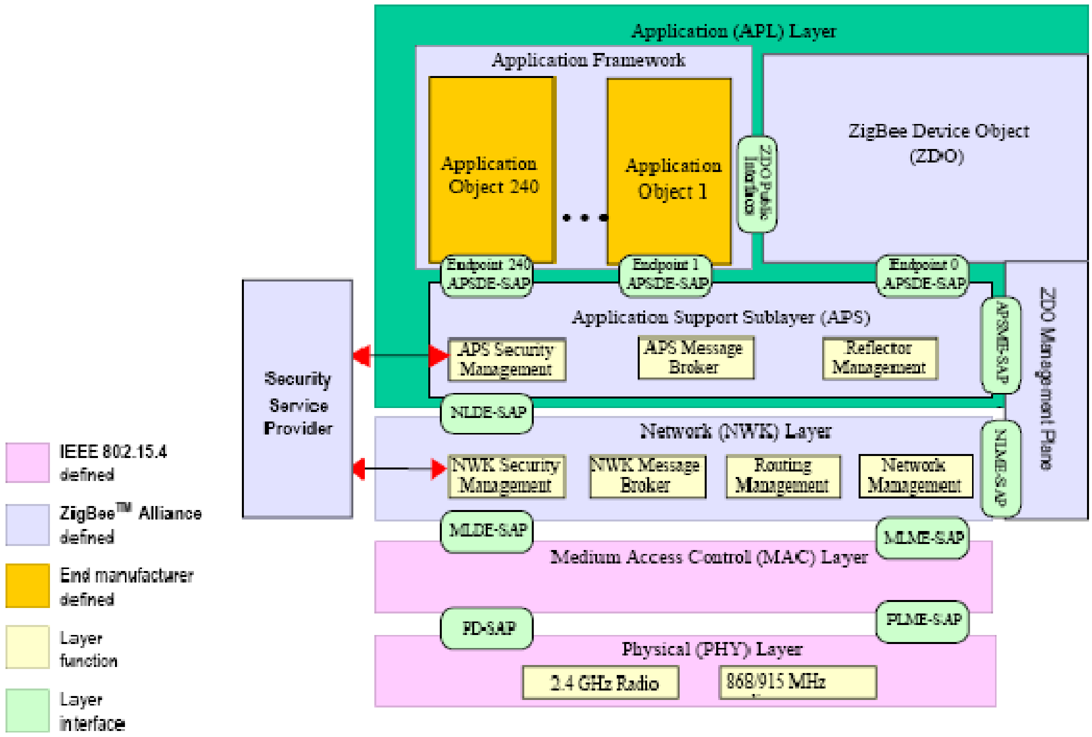

Figure 5: Zigbee stack architecture. (Aliance, 2003)

The IEEE 802.15.4 standard defines two different types of devices: the full-function device, FFD, and the reduced-function device, RFD, and three protocol device types: coordinator, router and an end device. If a network is created, it must have a single coordinator and one or more end devices can be used to perform monitoring, the use of a router is optional. The FFD can operate as coordinator, router or end device. The end device is the only protocol device that can operate as RFD. Zigbee uses two types of topologies: star and peer-to-peer topology (IEEE, 2003).

The star topology consists, basically, in one coordinator and in one or more end devices. The end devices only communicate with the coordinator. Therefore, if an end device wants to send information to another end device, this information must pass by the coordinator (see figure 6).

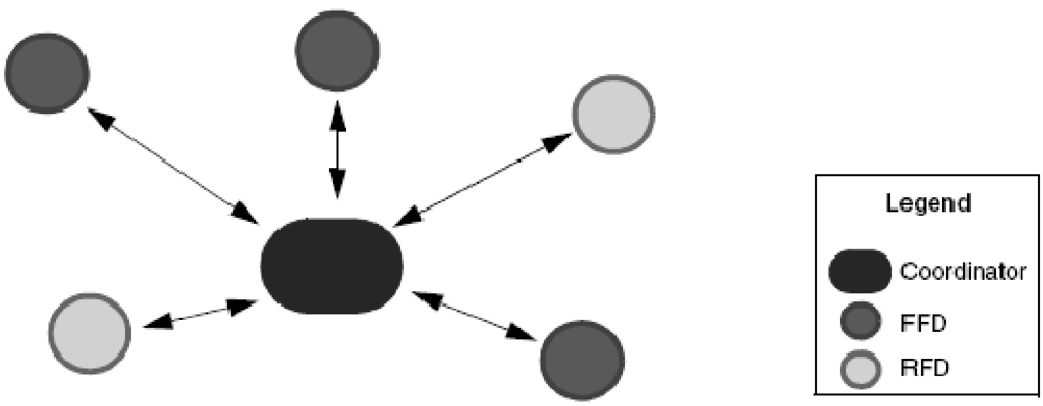

Figure 6: Star topology (Rajbharti, 2007).

In the peer-to-peer topology can be identified two different configurations. The difference is the use, or not, of the end device FFD to communicate, directly, with another end device FFD. When the end device FFD is not used to communicate, directly, with another end device FFD the configuration of the network is a cluster tree (see figure 7). When this occurs the configuration is a mesh network (see figure 8). In the peer-to-peer topology, the routers are used and have as function gives the possibility of increase the number of end devices in the network and increase the range of the network. The routers function as coordinator's extension. Therefore, the end devices can enter in the network by a wireless linkage to the coordinator but also with a wireless linkage to a router of the network. The mesh network configuration allows a lower latency in the message transmission and an increase in the message's reliability.

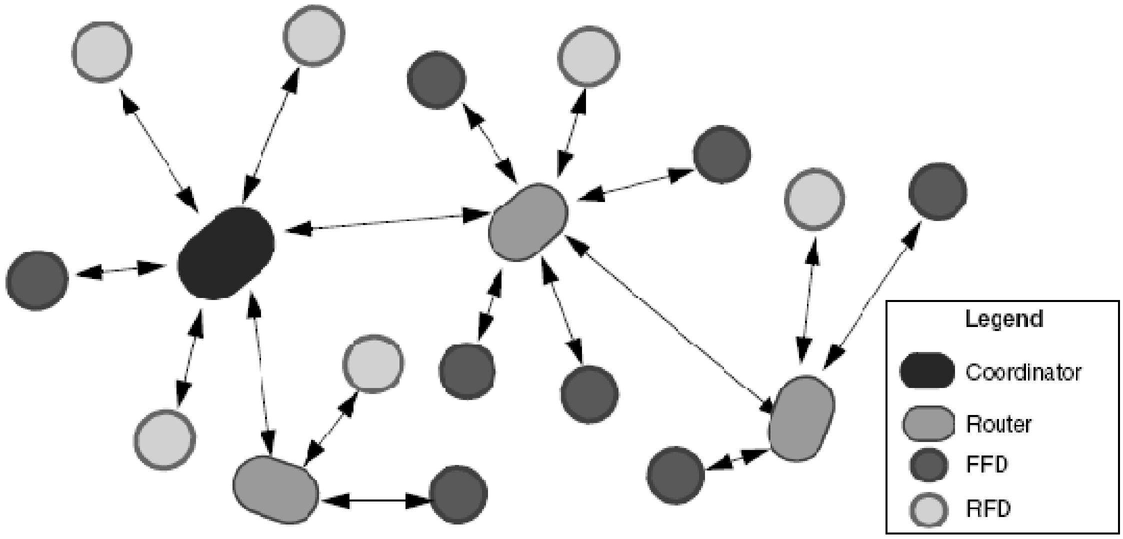

Figure 7: Cluster tree configuration (Rajbharti, 2007).

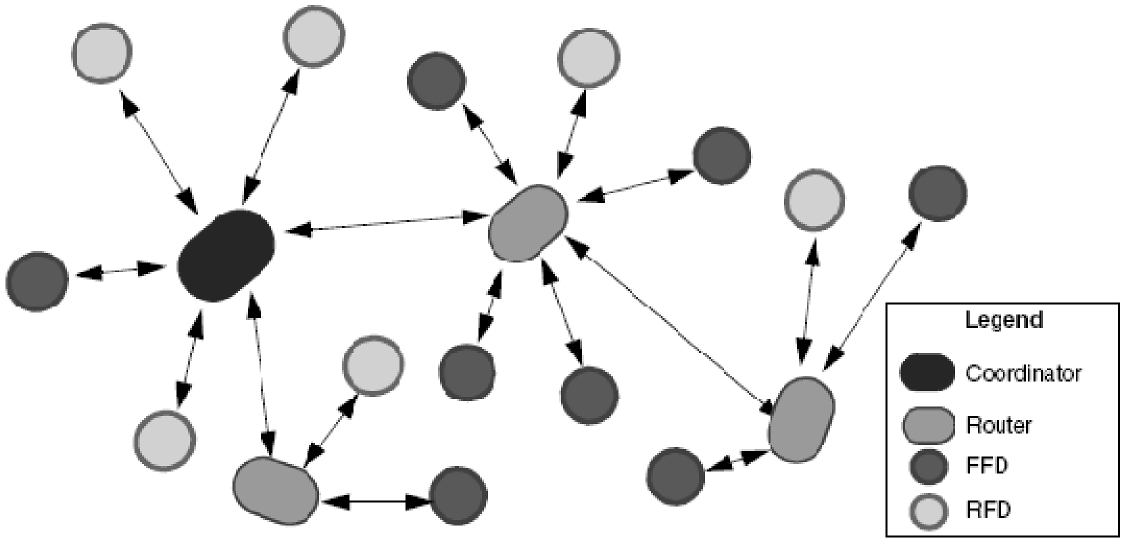

Figure 8: Mesh network configuration (Rajbharti, 2007).

Chapter 4
4. State-of-the-Art

The implementation of new technology, like wireless communications for accompany patients remotely, has allowed the creation of new companies. These companies imagined and created solutions, thinking in a specific cluster. Therefore, many different services/products appeared in the market in the last few years.

Beyond the companies, there is investigation in some universities of the world. The investigation, in the universities, has, many times, partnerships with others institutions and, sometimes, even with companies.

In this chapter, the objective is to understand the actual state-of-the-art in the area of telehealth and what are the strongest and weakest points of each system.

4.1. LifeGuard

This system, developed by the NASA Ames Astrobionics and by the Stanford National Biocomputation Center, was conceived to be used, at the beginning, in aerospace missions. The system was designed to follow the evolution of the astronauts' health (see figure 9). Despite the system to be, initially, used by the NASA for a unique purpose, quickly he was adapted and used for healthcare services.

The Lifeguard system has three major components:

- The sensors used to measure physiological parameters;
- The CPOD. A unit that receive data from the local sensors;
- A Device that receives data sent by all CPOD.

The sensors used in the system are:

- A pulse Oximeter. This sensor allows to know SpO_2 and heart rate;
- A temperature sensor;
- 3-Axis accelerometer for activity determination;
- A sphygmometer for blood pressure measurement;
- An electrocardiograph with six electrodes.

The system allows the use of the really necessary sensors for acquire the desired vital signs. Of all this sensors, only the 3-axis accelerometer and the temperature sensor are fully integrated in the CPOD. The others sensors are connected, to the CPOD, by cable. The CPOD receives all data from the local sensors, physically, connected to him. He can record and he is capable to send these data to a unit/device where the data can be analyzed and stored. This data transfer can be made by cable or wireless. The CPOD unit has two distinct ways of work:

- The first uses the flash memory, inside the CPOD, to record all collected data. This process is repeated since begin until the end of the acquisition. When occurs the end of the acquisition, the data can be downloaded to a device, by a RS-232 cable, where the data can be analyzed and stored;

- The second is used for real-time tracking. In this case, the data are sent wireless, by Bluetooth or 916MHz FSK technology. In each CPOD only one of these two wireless technologies is available.

The unit, that receives the CPOD's data, must support RS-232 and both, Bluetooth and 916MHz FSK, wireless technologies to communicate. In every single moment, the unit can communicate with only one CPOD. The unit has integrated software with some algorithms. These algorithms allow to the healthcare provider to see the general evolution of the patient's clinical status or select and extract specific information.

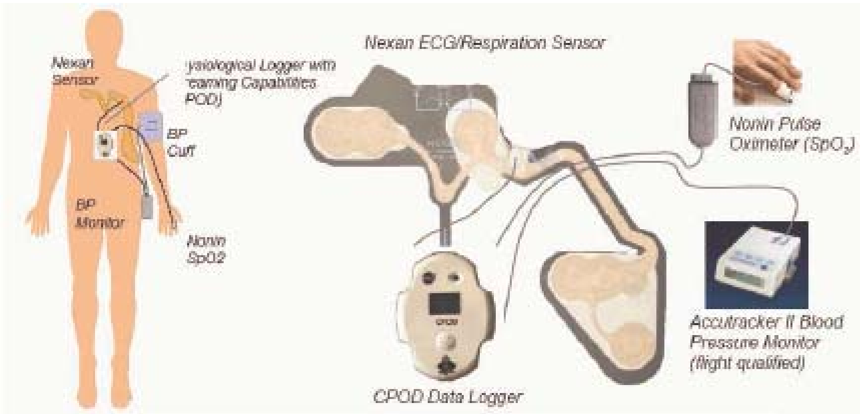

Figure 9: Lifeguard architecture (Lee, 2005).

4.2. CodeBlue

Codeblue is a project developed, in a partnership, by several institutions. Some of these institutions are the Harvard University, the Boston Medical Center and the Intel Digital Health Advanced Technology Group. The main objective of this investigation is the creation of a system capable of cover some medical situations, like pre-hospital and in-hospital emergency care.

This system uses a wireless Oximeter (see figure 10) and a 2-lead ECG to collect data and extract information about heart rate, SpO_2 and heart function behavior. Other sensors developed will permit monitoring the limbs' movements and muscle activity of stroke patients during rehabilitation exercise. These sensors are the 3-axis accelerometer, gyroscope and an electromyogram.

The sensors are capable of sending data by wireless technology up to 100 meters, with Zigbee technology, to PDA, laptops or ambulance-based terminals in real time. Another feature, supported by the sensors, is the capability of to be programmed for analyse data and send an alarm if necessary. Integrated in the sensors hardware, it exist a GPS modem. This GPS modem allows to the healthcare provider know where the patient is.

The Codeblue system is implemented in a mesh network. The mesh network uses a publish/subscribe data model. In this data model, sensor nodes publish vital signs, location and identify, the rescue/medical personal subscribe to data of interest and the devices cooperate to route data from publishers to subscribers.

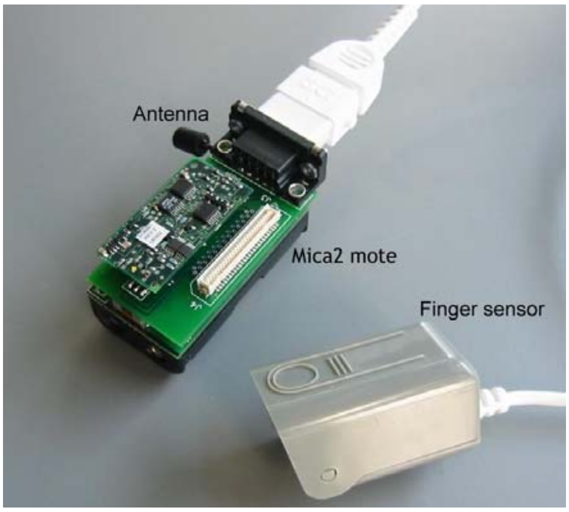

Figure 10: A wireless Oximeter from the Codeblue Project (project, 2006).

4.3. Mobihealth

The MobiHealth system is a project with support funds of the European Union. The system is the result of a partnership between several companies, like the Ericsson, the Telefonica, the Philips and the University of Twente. The objective was to use a BAN for establish communication between a device and a central unit, without the use of wire technologies. Therefore, the communication was established with a wireless technology. The technology chosen was the Bluetooth. If it is necessary establish communication between a device of the BAN and another out of this BAN, a different wireless technology is used. In these cases, the Mobihealth system uses a GPRS or UMTS technology. The communication, between a device of the BAN and another out of this BAN, is made by a MBU. A MBU is, basically, a PDA with the function of a gateway.

The healthcare system, MobiHealth, has three main components:

- The sensors. The system is capable of support several sensors. They are:
    - Pulse Oximeter;
    - ECG 3-lead;
    - Sphygmomanometer;
    - Body weight scales;
    - Capnography;
    - PEF meter;
    - Glucometer;
    - Coagulation Monitor.

  Depending of the sensor, they are able to acquire in continuous or in discrete mode. The collected data are sent with Bluetooth technology.
- An Ericsson P910. This unit receives all data acquired by the sensors. After the data arrive, by Bluetooth technology, he transmits the data to a central server. The communication is established with GPRS or UMTS technology. This device can

interact with the patient and he allows to the patient to make registers of his clinical evolution.

- The Central Server. The Central Server is the work station where the data are stored and managed. The data can be view in the web, only by authorized personal. The access, to the restricted area, has some security levels.

When a healthcare provider enters in the website, he can view the data in a graphic representation and historic events. They can, also, to define alerts in the Central Server and send to the patient. The alerts can be set for a medication alert or to make a specific data acquisition. If the alert wasn't delivered successfully, the healthcare provider will know.

However, this system has some problems. The bandwidth is too small for the traffic generated by the sensors, when the system uses Bluetooth technology.

4.4. CardGuard

CardGuard is a company of healthcare technologies. One of his services/products is the system PMP4. The system PMP4, like the previous systems, is wireless based. One important feature of this system is the option, for the healthcare provider, of interaction with the patient, in real time.

The system is versatile in their communications because he can use several wireless technologies, like Bluetooth, GSM-GPRS and Wi-Fi. The PMP4 can communicate with a PDA, cellular phone, interactive television or a PC. The sensors used are an ECG, 1 to 12 leads, a spirometer, a glucometer, an Oximeter and a weight scale. The PMP4 system allows healthcare monitoring at patient's home. Data, from this system, are sent for the data management Center. Here, the data are analyzed, processed and stored.

Chapter 5
5. Requirements Analysis

With the objective of build our own system, it is necessary identify first, the real needs of the market. Know the physiological parameters, of high relevance, for the healthcare provider and how the collected data must be showed. Identify the best solutions to transmit the data and the information, in general.

With this information and with the study made in the state-of-the-art, it is possible to discuss which the best design for this project. Along this chapter, it will be discussed the vital signs chosen for acquisition and the strategy followed in the design of the project.

5.1. Acquisition Module

The process of data acquisition begins here. When this module receives the order to begin data sampling, he is able to know which sensors are connected and which sensors aren't connected. In this way, the sensors only acquire data where exists a sensor placed. At the same time, it is possible the existence of more than one of these modules working in the same person.

Next, it is presented the physiological parameters chosen to be monitored in the system and how this information is transmitted.

5.1.1. Physiological Parameters

5.1.1.1. ECG

ECG is a graphic representation of the heart electric activity. The information, given by the ECG, is very useful because it allows knowing heart rate and, when analyzed by physicians, to understand if there are, or not, heart malfunctions. The ECG will have three leads and the heart rate sampling will be 100Hz.

5.1.1.2. SpO2/Heart Rate

For the acquisition of these physiological parameters, it is necessary the use of a oximeter. The oximeter is the result of the application of a non invasive technique for measure the blood oxygen saturation. The measurements take place in a thin area of the human body, like a fingertip or one of the earlobes. In this technique, they are used two different LEDs. One LED emits photons with red light and the other emits photons in the infrared spectrum. To collect the reflected or transmitted light, a photodetector is used by the oximeter. With the application of an algorithm, it is possible to know the blood oxygen saturation, in percentage. The oximeter has, also, an algorithm to extract information about heart rate. Current oximeters have, already these algorithms in his hardware and the data are digital. Therefore, it is only necessary read the transmitted data by the device.

5.1.1.3. Posture/Activity

The person's activity can be measured by using an accelerometer. An accelerometer is an electronic device for measuring acceleration, detecting and measuring vibrations and for measuring acceleration due to gravity. There is more than one type of accelerometer but, for our project, will be used a 3-axis accelerometer.

The process of measurement is not direct. Instead, changes in the accelerometer relative position affect the voltage at the terminals. Faster changes induce more acceleration and the voltage at the terminals is higher.

5.1.1.4. Temperature

The temperature is a consequence of all, internal and external, activity of the human body. To take a good temperature measurement, it is necessary put the sensor in appropriated places in the human body. These places are the armpits, the groins and the auditory canal. However, for the system the thermometer will be put in other place, more peripheral.

In all human bodies the average temperature is 37ºC, with little fluctuations in normal situations. When occur a bigger fluctuation, it is an indicator for the healthcare provider that the patient is sick.

5.1.2. Communication

The collected data, by the acquisition module, must be transmitted for another electronic device, the transmission module, once he has data memory with little space. The communication, between these two modules, is wireless. However, there are several wireless technologies and some specific requirements, of the system, must be respected. Choose the correct one is critical step. Some of the requirements are:

- Amount of data;
- Security;
- Power consumption;
- Wireless interference;
- Distance between modules.

5.1.2.1. Traffic

In this section is discussed the amount of data acquired by the acquisition module and the acquisition's frequency, in each sensor.

Sensor	Acquisition's frequency (Hz)	Amount of data (bytes/s)
ECG	100	200
Accelerometer	1	6
Thermometer	1	2
Oximeter	1	(N1+N2)

Table 2: Amount of data acquired in each sensor. Once the oximeter wasn't chosen this information it is not available. Therefore, N1 represent data about the SpO_2 and N2 represent data about the heart rate.

In the table 2, it is possible to see the amount of data acquired in each sensor. The ECG is the major responsible by the amount of the acquired data.

Because of the power consumption, the data are sent in packets. One packet has 208+N1+N2 bytes plus the temporal information, 6 bytes of the RTC, about the instant that the data were acquired.

5.1.2.2. Wireless Technologies

To establish how both, acquisition and transmission, modules exchange information, must be studied the different wireless technologies (see table 3). Once both modules are close each other, at the maximum distance of 5 to 10 meters, the wireless technologies are WPANs.

The WPANs studied are the Bluetooth and Zigbee technologies. In the next table, it is possible to know the features o each one.

One important factor, in the choice of the right wireless technology, is the implementation of each one of these technologies in the market. After some meetings for discussion of this issue, the best choice, to the system, will be to use both technologies although, at the same time, only one is in the hardware.

Features	Zigbee (IEEE 802.15.4)	Bluetooth (IEEE 802.15.1)
Range (meter)	10 to 100	Class I - ≈100 Class II - ≈10 Class III - ≈1
Power Consumption Transmission* (mA)	35	40
Power Consumption Standby* (µA)	3	200
Frequency Band	≈868MHz (Europe) ≈915MHz (USA) ≈2.4GHz Global (ISM)	≈2.4GHz Global (ISM)
Network Topologies	Star, Peer-to-Peer	Piconets
Number of devices per Network	2 – 65000	8
Bandwidth	20 – 250 Kbps	V2.0 – 2,1Mbps

Table 3: Features of the Zigbee and Bluetooth technologies.

5.2. Transmission Module

When a patient is under monitoring, with the use of the Acquisition Module, is important make arrive the information to a final destination, the Data Center. To do this task, it is necessary the use of a second module with a highest range, the Transmission Module. In the next section will be describe how the Transmission Module must work.

5.2.1. <u>Operation Modes</u>

The transmission module must be capable of to have two operation modes:

- Real-Time Monitoring – In this mode the received data are immediately sent to the Data Center;
- Offline Monitoring – The transmission module receives the data from the acquisition module and store the data in his local data memory. When the monitoring session is finished, the data memory is read and the data are sent to the Data Center.

5.2.2. Data Storage

The transmission module must have data memory capability. With a data memory, the transmission module is capable of stored data and work, properly, in the two operation modules. This module allows store data:

- As a backup. This can be useful when a data transmission, for the Data Center, fails;
- For algorithms application. These algorithms can detect anomalies and send an alarm to the Data Center;
- In Offline Monitoring Operation Mode.

5.2.3. Communication

Beyond the communications with the acquisition module, the transmission module must be able of communicate with the Data Center to exchange messages. In the case of the communications between acquisition module and the transmission module, this issue was, already, discussed in the previous chapter, about the acquisition module.

The communications, between the transmission module and the Data Center, depends where the patient is. In one of the situations, the patient is in the hospital and in the other situation, the patient is at home.

5.2.3.1. Hospital Monitoring

A released study, in the year 2006, by the INE and the UMIC, with the purpose of analyse the implementation of the ICTs at the hospitals, publics and privates, in Portugal, shows that 33,8% has wireless LAN in their buildings. A second study, made by the project's students, suggests that these hospitals, when they have wireless LANs in their buildings, have as main technology the Wi-Fi. However, the implementation of this wireless technology in the building, sometimes, is not homogenous but, in the most of the cases, the rooms where the inpatients are have, or will have shortly, wireless covering.

With these studies in mind, the logical wireless chosen is Wi-Fi, to establish communication between the transmission module and the Data Center. In the next table, some features of the Wi-Fi are indicated.

IEEE Standard	Frequency Band	Range	Bandwidth	Standby Consumption	Transmission Consumption	Network Topology
802.11b	2.4GHz	<100 meters	2 – 11 Mbps	20mA	>400mA	Mesh, access point

Table 4: Features of the Wi-Fi wireless technology.

5.2.3.2. Residence Monitoring

When the patient leaves the hospital but is necessary keep the surveillance in their physiological parameters, the transmission module must be capable of communicate with the Data Center. In this situation the wireless technology Wi-Fi can be useless because the range is not good enough.

To make possible exchange information between the transmission module and the Data Center, another wireless technology must be used with a range capability of kilometers and not meters. This wireless technology must be capable of support the dataflow exchanged between the transmission module and the Data Center. In the following table are presented some features of the technologies studied.

Features	GSM/GPRS	UMTS W-CDMA R99
Max Down Link (Kbps)	81,92	393,22
Max Up Link (Kbps)	40,96	393,22
Typical Down Link (Kbps)	14,33	199,68
Coverage	Almost all the Country	Only Urban Areas

Table 5: Features of the wireless technologies studied for residence monitoring.

With the support of a study, made by the INE and UMIC,, it is possible to know what are the hospitals where the telemedicine services, including telemonitoring, are applied. It is in non-urban areas that these services are more used. Like the table 5 shows, in the present day the UMTS technology exists mainly in the urban areas. By the other side the GSM/GPRS has capability to support data transfers between the transmission module and the Data Center in all the national territory. With this information, the wireless technology chosen was GSM/GPRS. When in working, the transmission module only can have one of the two wireless technologies available; although each machine has the capability two support the two technologies.

To make the system more versatile, the transmission module will have a wire transmission capability. The interface is USB and is capable to connect the transmission module to the Data Center.

5.3. Data Center

The Data Center is the final destination of all data, coming from the transmission modules, for both Hospital and Residence Monitoring. Because of this, the Data Center must be capable, at the same time, of communicate with the transmission module in any wireless technology, Wi-Fi or GSM/GPRS, study for this device. The Data Center, also, must have an USB physical connection to receive data from the transmission module.

All the process will be with a request-confirmation communication. The communication can begin in:

- The transmission module. In this situation, when the transmission module is power-up, the communication is started. After establish connection with the others modules, acquisition and Data Center, the process of acquisition of the physiological parameters begins.
- Data Center. In this situation, the healthcare provider in charge has the responsibility of initiate the process. Messages are sent for the transmission module and after the confirmation message to arrive the process begins.

When data arrive, they are stored together, in the patient profile, in a database. This database allows the healthcare provider watch the clinical situation of the patient, live or the historical. The physician or another healthcare provider, also can be capable of access to the database without be at the host computer. To do this, the Data Center must be capable of communicate with others devices, like PDAs, or remote PC.

The system has a login area where the healthcare provider must make the register, to ensure that only authorized personal has access to the information. For this project the communications, always, begin at the Data Center.

Chapter 6

6. System Architecture

Before start to programming the transmission module and the acquisition module a plan is necessary. This plan will allow a better identification of all possible situations that can appear in the future. To do the plan, an analysis must be done and three main tasks exist:

- The first task is to identify all the needs of the healthcare provider. Their needs are present in the Data Center, when the professional like to see some specific information. To identify all the needs, a skin of the Data Center must be made;
- The second task is to establish the rules of communication between all the modules. Since the acquisition module does not communicate, directly, with the Data Center, only two communication protocols are necessaries. One establish the rules of communication between the Data Center and the transmission module and the other establish the rules of communication between the transmission module and the acquisition module;
- The third task is to create the flowcharts for the internal functionalities of both, transmission and acquisition, modules. These flowcharts must show how the modules work in normal situations but also how problematic situations will be resolved.

6.1. Data Center Skin

The Data Center is a software program where only authorized personal, like physicians and nurses, has access to the information. This computer program allows, to the authorized healthcare providers, the surveillance of the patients, inpatients and outpatients, without a closer contact.

As discussed before, the decrease of the ratio, healthcare providers vs. patient ratio, decrease the time that the healthcare provider can give for survey each patient. Therefore, it is more and more necessary a solution that can resolve these problems. A good Data Center allows the healthcare provider watch all the patients in one single room but, also, in other physical place, as in physician officer (with internet access). A full versatility of the system is the capability of the healthcare provider can watch the vital signs evolution in any place of the hospital. This can be made by using portable electronic devices with wireless access to the Data Center network, as a PDA.

The Data Center Skin will show an idealization of the Data Center interface and what functionalities the healthcare provider will like to choose. With the identified functionalities, the transmission and acquisition modules can be designed to satisfy all the needs.

6.1.1. Login Area

When someone wants access to the Data Center must have permission. The system checks the permission of the healthcare provider by the combination username/password introduced. If the combination username/password is a valid one then the healthcare provider enters in the Data Center (see figure 11). However, the Data Center has two levels of access:

- One of the levels is for the administrator. Only few, or even one, person can be administrator. As administrator, he manages all the accounts (delete, create and change) and he can know the list of healthcare provider that are allowed to login. He has all the functions of a normal healthcare provider. The systems enters in the Administration Page;
- The other level is for general healthcare providers with Data Center access permission. From here he goes to the Healthcare Provider Login page.

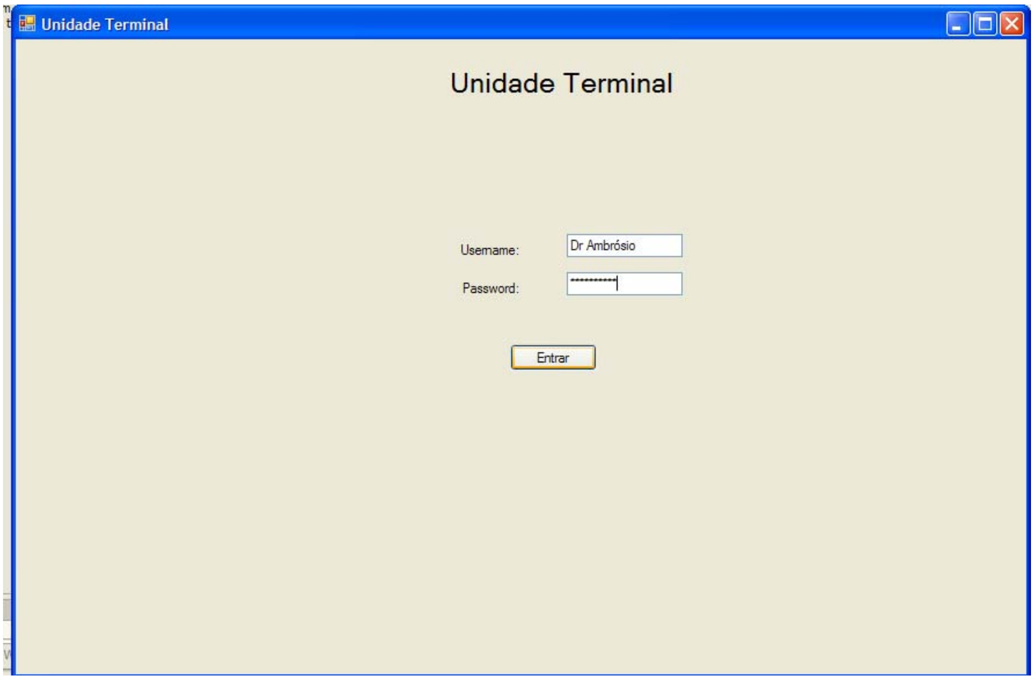

Figure 11: Initial page for healthcare provider login.

6.1.2. Healthcare provider Login

After a successful login, the healthcare provider can see information about the time and date of login, in the left inferior corner and the option of logoff (see figure 12). When the logoff option is selected, a confirmation message appears. If he presses "*Sim*", the Data Center goes to login page. If he presses "*Não*", the action is canceled. In the first situation, if the page for the creation of a new patient's file or the creation of a new monitoring session is open, a second message appears to ask if these processes are cancelled. If he presses "*Não*", the logoff action is canceled. If he presses "*Sim*", the Data Center goes to login page. Along the left side of the interface, the healthcare provider has the following functionalities:

- The highest window has the name of the patients, in the moment, in vital signs acquisition. If the healthcare provider makes double click in one of the names, the system opens the patient's file;
- If it is necessary register a new patient then the healthcare provider must choose the button "*Criar Ficha Paciente*". He goes to the New Patient's File page;
- If the healthcare provider wants to open an existing file, of an already registered patient, he must choose the button "*Abrir Ficha Paciente*". He goes to the Open Patient' File page;
- The lowest window has information about all the alarms received by the Data Center. Each alarm shows the name of the patient, date and time of the alarm and a "LED". A green led represents a response to the alarm. If double clicked the system open the patient's file. A double click sends the healthcare provider to the Patient's File page. A flash red led represents an alarm without a taken response. If double clicked the system open the visualization session page of the patient. A double click sends the healthcare provider to the Graphic Monitoring page.
- When the healthcare provider opens a patient's file, information about the patient, the name, appeared below the text "*Paciente Actual*".

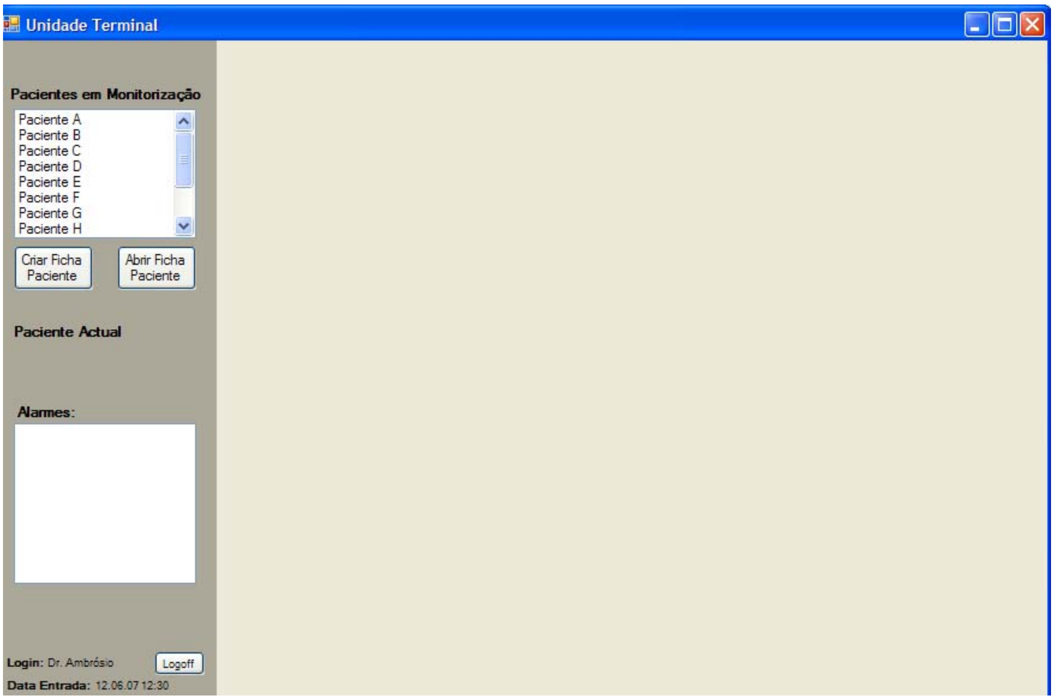

Figure 12: After the login, these are the options of the healthcare provider.

6.1.3. Administration Page

The administration page is the same of the healthcare provider login with a single different (see figure 13). A button, "*Admin*", to the management page is above the logoff button.

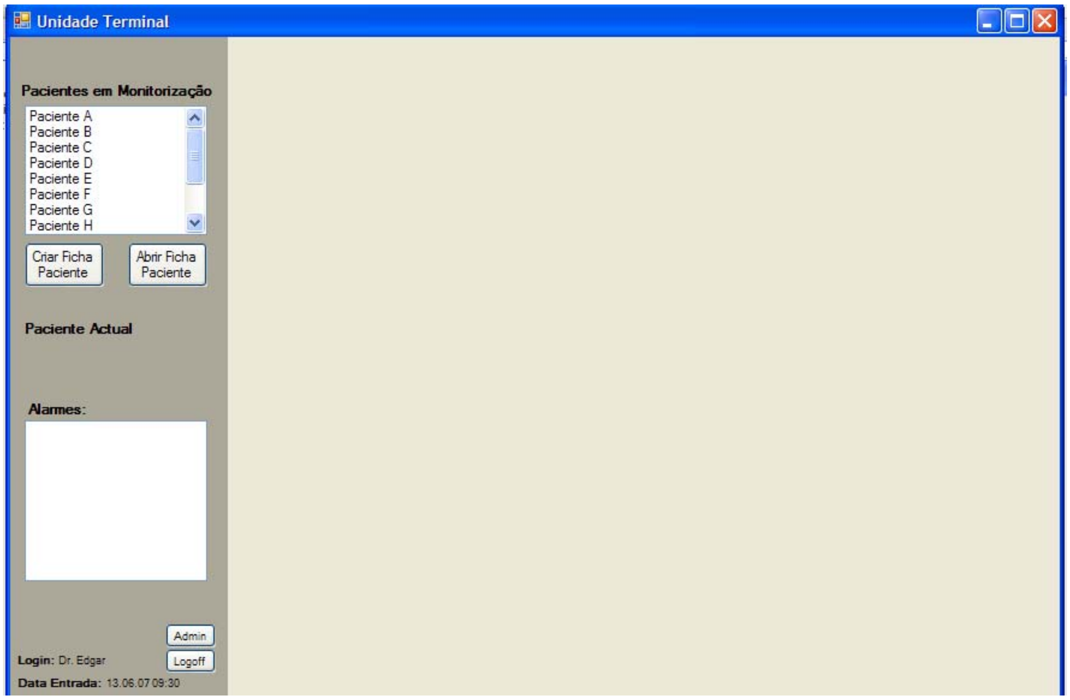

Figure 13: Administration page.

6.1.4. Management Page

The Management Page is the place where the administrator can do the work only authorized to him with four main functions (see figure 14). There are:

- New Access Account. The data information required are:
    - Name;
    - Internal ID;
    - Function;
    - Username;
    - Password;
    - Password Confirmation.

When the administrator presses the button "*Criar*", the system checks if any field is empty, if the Password and the Password Confirmation fields have the same information and if this account already exists. If any field is empty or the Password and the Password Confirmation fields haven't the same information or the account already exists a "warning" message is showed and access account is not created. If everything is alright a new access account is created.

- My Account. If the administrator wants change is password, he only must write the old password in the first field and the new password in the second and third field. When he presses the button "*Alterar*", if the second and third fields have the same information, a new password is set. If the second and third fields haven't the same information the new password isn't set and a "*warning*" message is showed;
- Access Account List. In this list appeared:
  - Healthcare provider name;
  - Function;
  - Internal ID.

The selection of one name on the list allows the selection of the button "*Apagar*". If the button is pressed a confirmation message appears. If he presses "*Sim*" the account is deleted. If he presses "*Não*" the deleting process is cancelled.

- Historical Access. A list with all logins is available. This list contains:
  - Username;
  - Date Login;
  - Date Logoff.
- In the right inferior corner, the button "*Voltar*" allows the administrator return to the Administration Page.

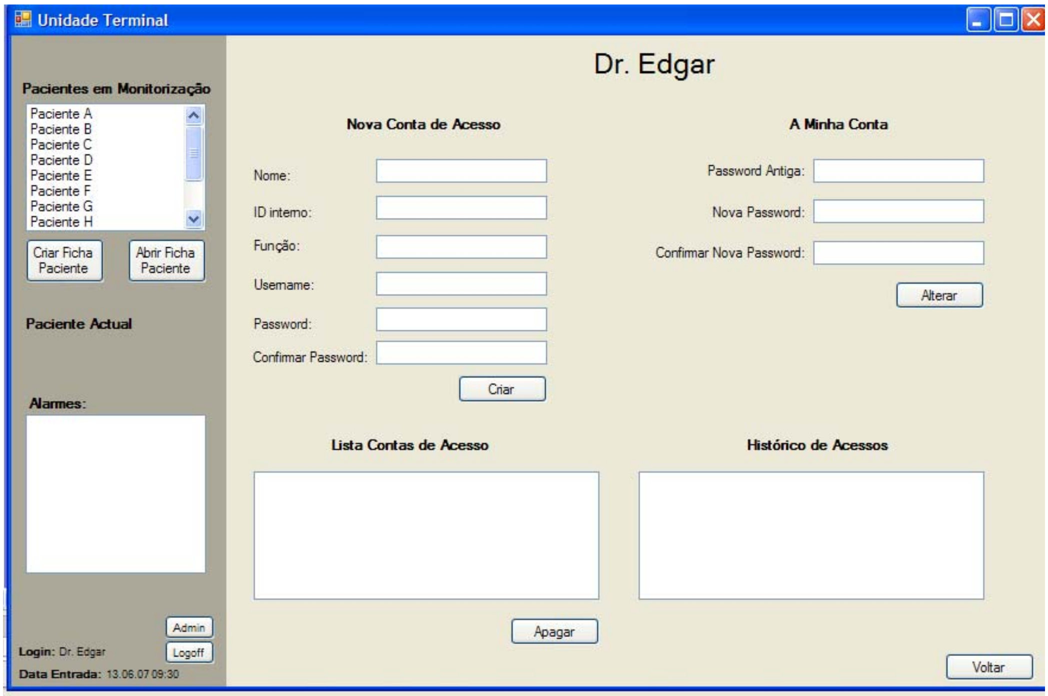

Figure 14: Restricted area. Only the administrator has access to this page.

6.1.5. New Patient's File

When the healthcare provider enters in this page, to create a new patient's file, he must fill all the fields. They are:

- Patient's Name;
- Internal ID – An internal designation for the patient;
- Transmission Module's ID – Designation used with the objective of an automatic attribution when the transmission module power-up;
- SNS number;
- Sex;
- Birthday;

An observation field can be used for clinical historical. The fill of this field is optional. After all fields, less the observation field, are filled the healthcare provider presses the "*Ok*" button, the patient's file is created and he goes to the New Monitoring Session page. If he presses the "*Cancelar*" button, the action is stopped and the system returns to the Healthcare Provider Login page.

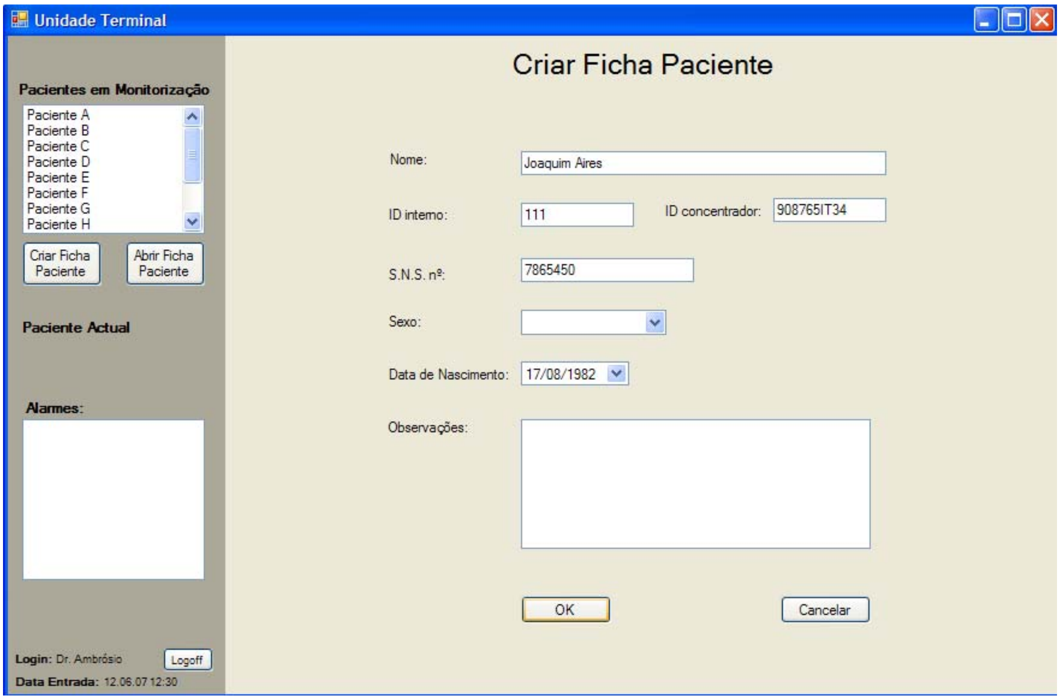

Figure 15: The process of patient's file creation.

6.1.6. New Monitoring Session

When a new monitoring session is created some options must be taken. The healthcare provider must choose between a live session and an offline session, the desired sensors and the definition of alarms. The alarms are for the temperature and oximeter sensors, but only available in live session mode. In the temperature alarm, the healthcare provider must choose the temperature limits. Above and below these values an alarm will be sent to the Data Center. For the oximeter sensor, two signs are acquired, and two alarms can be set. One alarm can be sent for the SpO_2 with the lower value acceptable. After a minimum time of waiting, the sensibility, an alarm can be sent to the Data Center. The second alarm is for the heart rate. The healthcare provider set the maximum and minimum heart rate permitted. Above and below of these values an alarm is sent to the Data Center.

After the configurations are finished, he pressed the "*Iniciar Monitorização*" button and the system goes to the Graphic Monitoring page. If he pressed the "*Cancelar*" button, the system returns to the Patient's File page.

Figure 16: The creation of monitoring session with the possibility of managed the desired sensors and the alarms definitions.

6.1.7. <u>Graphic Monitoring</u>

The system uses three different areas to see temporal evolution of the vital signs. In the:

- Area 1 is possible to see the ECG evolution;
- Area 2 is possible to see the SpO_2 evolution;
- Area 3 more than one vital sign is possible to see. Temperature, posture/activity and heart rate are the physiological parameters that can be seen. At the same time, one single vital sign can see.

In area 1 and area 2, it is possible to see:

- Monitoring in real time;
- The older data by the use of the horizontal *scroll* bar.

In the area 3, it can be seen the temporal evolution for the selected vital sign. The healthcare provider can choose the desired information by pressing one of the arrows on the left side of area 3. As in the case of area 1 and 2, all the data, of the session, can be seen. The most recent data appear at the screen but, the older data can be seen by using the horizontal scroll bar. At the left side of the arrows there are monitors where the evolution of the physiological parameters can be seen, in a numerical representation.

At the right side of the interface program there are two list boxes. The upper box has the alarms to the SpO_2 and the lower box has the alarms to the temperature and heart rate. For both boxes there is a button, “*Alarme Verificado*”. When an alarm is selected and if he hasn’t a response confirmation, the button turns available. If he presses the button the alarm is checked and changes his status. Each alarm has information about the date and time of the alarm and a LED, as decribed in Healthcare Provider Login page.

The offline monitoring is a particular case. When chosen some functionalities are changed. The alarms lists disappeared, the monitors don’t show temporal information, only a reference to the vital sign showed when the arrow at the right is pressed.

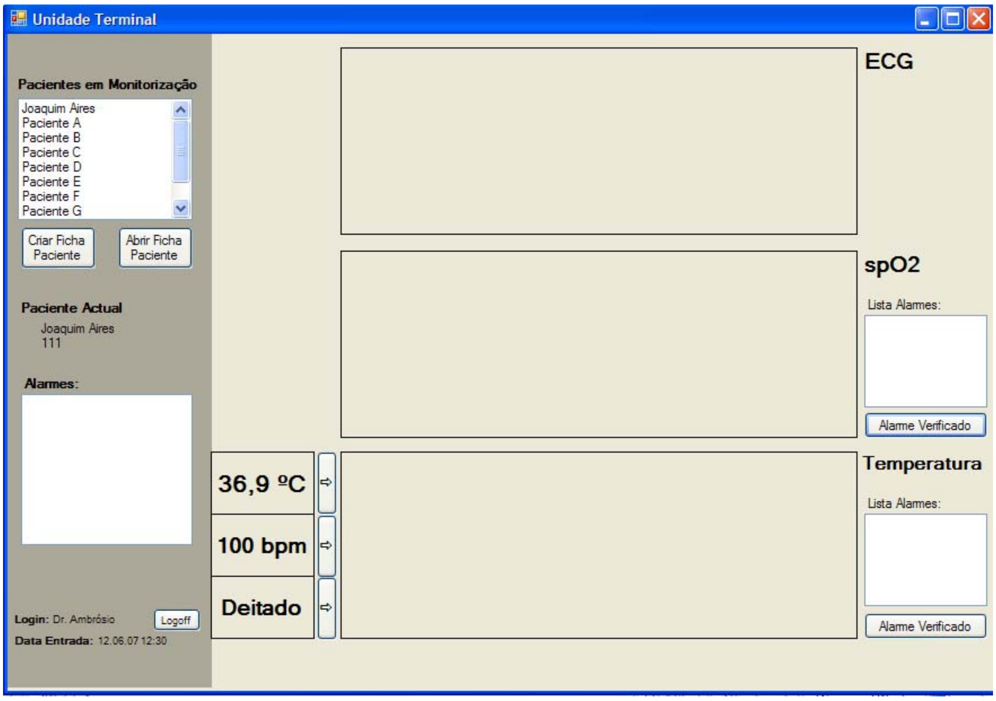

Figure 17: The heart of the system, where the healthcare provider watches the patient evolution.

6.1.8. Patient’s File

The access to the patient’s file allows know the personal information of the patient, the internal information attributed to this patient and the generated alarms. The alarms are in a list box and each alarm has information about:

- Psysiological Paramenter;
- Date and time information about the instant that the alarm was generated;

- Who respond;
- Date and time of the response.

Other functions are present in this page. If:

- Exists a monitoring session in the moment then it is possible:
  - o Press the "*Ver Monitorização*" button and he enters in the Graphic Monitoring page;
  - o Press the "*Terminar Sessão de Monitorização*" button and end the monitoring session;
  - o The "*Iniciar Nova Sessão de Monitorização*" button isn't available.
- No exists a monitoring session in the moment then it is possible:
  - o Press the "*Iniciar Nova Sessão de Monitorização*" button and he enters in the New Monitoring Session page;
  - o The "*Ver Monitorização*" and "*Terminar Sessão de Monitorização*" buttons aren't available.
- In the alarm list, the healthcare provider can make double click in one of the alarms and he enters in the Graphic Monitoring.

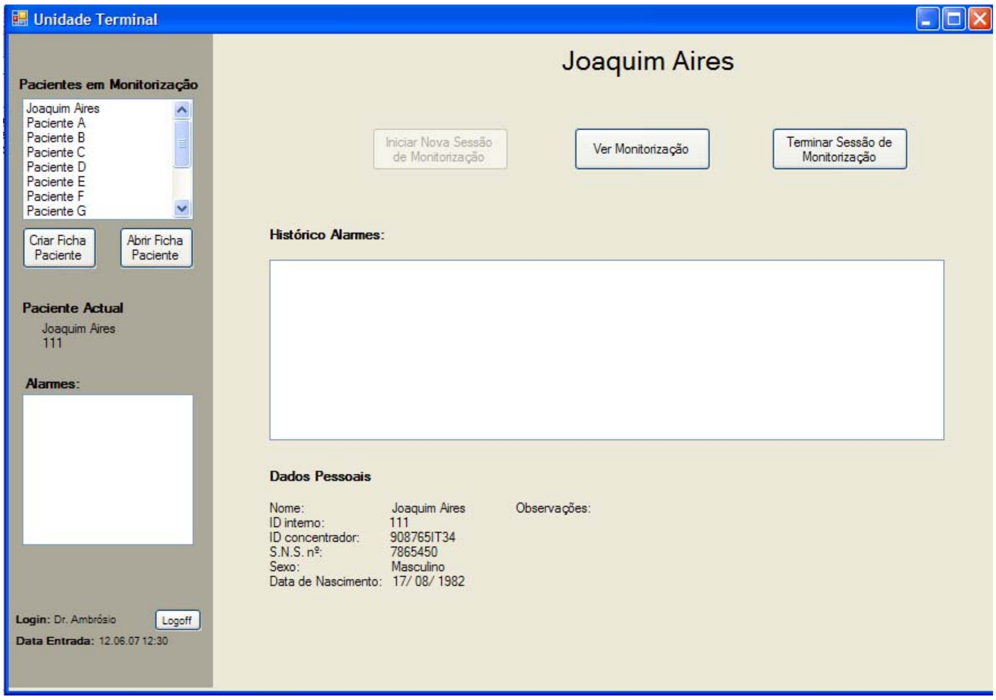

Figure 18: The patient's file.

6.1.9. Open Patient's File

The open patient's file page allows to the healthcare provider have a list of the registered patients that, in that moment, aren't to be monitoring. When a patient is selected, from the list box, his personal information appears at the right side of the list box. In this moment the "*Abrir*" and "*Cancelar*" buttons are available. If he presses the

"*Abrir*" button, the system goes to the Patient's File page. If he presses the "*Cancelar*" button, the system goes to the Healthcare Provider Login.

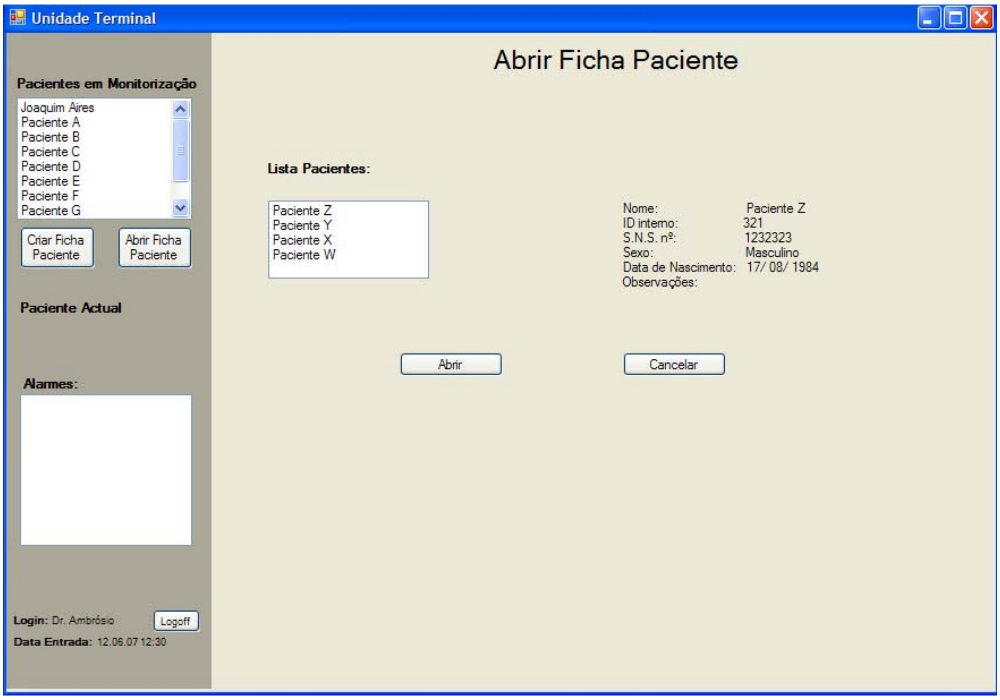

Figure 19: Information's page about the patient registered but that don't have a session monitoring active.

6.2. Communication Protocols

In this section will be discussed how the three parts of the system, Acquisition Module, Transmission Module and Data Center, communicate. Once the Data Center doesn't communicate with the acquisition module, only two communication protocols are necessaries. First, it will be presented the communication protocol for the transmission module and the Data Center exchange information.

6.2.1. Data Center ⇔ Transmission Module

As discussed early, these two sub-systems will communicate with a wireless or a wire technology. For the wireless communication, the technologies chosen were the Wi-Fi, for a Hospital Monitoring, and GSM/GPRS, for a Residence Monitoring and for the wire communication, the technology chosen was the USB.

6.2.1.1. Header

All the messages must have a header. The header, for this situation, is a single byte and is at the top of the message. This byte carries the information about the type of message received. How it is possible watch, in the table 6, the first identification number, in this header, is one. Therefore, the header can carries 255 different messages.

Field	Description	Type	Size	Start Position
Type of Message	This field identify the message Range of values: [1…255]	Byte	1	0

Table 6: Header of the messages.

6.2.1.2. Transmission Module Identification Message

At the moment that the transmission module is power-up, he must connect to the Data Center. The transmission module can connect to the Data Center by USB cable or a Wireless technology. When power-up, if both devices are connected by an USB cable, the communication is established by the USB cable. If in the middle of the work the USB cable is disconnected, the transmission module will try connected by wireless technology and, if successful, the section continues. In the beginning, if no USB cable is connect both devices, the transmission module will try connect to the Data Center wireless.

This is an automatic process and the header message has the number 4 (see table 9). Once there are more than one technologies used, the message has a different composition.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Identification	Identification of the transmission module to the Data Center **IMEI** – Transmission Module with GPRS modem (see table 8) **MAC Address** – Transmission Module with Wi-Fi modem (see table 9)	---	---	---

Table 7: Identification Message from the Transmission Module to the Data Center.

If the communication is established by the GSM/GPRS technology the message sent has the header and, straight away the IMEI identification. This IMEI identification is unique and it allows identify the GSM/GPRS modem.

Field	Description	Type	Size	Start Position
IMEI	GPRS Modem Identification Range of values: 15 characters alphanumerical	ASCII	15	1

Table 8: Identification code for the Transmission Module when he uses GSM/GPRS modem.

If the communication is established by the Wi-Fi technology the message sent has the header and, straight away the MAC Address identification. The MAC Address is, also, unique and it allows identify the GSM/GPRS modem.

Field	Description	Type	Size	Start Position
MAC Address	Wi-Fi Modem Identification Range of values: 15 characters alphanumerical	Byte	6	1

Table 9: Identification code for the Transmission Module when he uses a Wi-Fi modem.

When the Data Center receives the message, he sends a confirmation message to the transmission module.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 10: Confirmation message sent to the Data Center.

6.2.1.3. Monitoring Session Beginning Request

Since it is the Data Center that initiates the communication, when a message is sent to transmission module, the first message that the transmission module receives from the Data Center, a request to begin the session is in the message (see table 11). The header of the message has the number one. In the message exists, also, information about the sensors chosen by the healthcare provider to acquire data. If a sensor is chosen he has number one attributed, if he is not chosen he has the number zero attributed. To ensure a non corrupted message, straight away to the sensors chosen, there is information, three bytes, for the application of an algorithm. The first byte is the sum of the three first sensors (ECG, Accelerometer and Thermometer), the second byte is the sum of the accelerometer and oximeter sensors and the third byte is the sum of the thermometer and oximeter sensors. The algorithm allows data integrity verification because he has a unique possibility for each combination (see appendix).

Field	Description	Type	Size	Start Position
Header	Header of the message, see table6	Byte	1	0
ECG	Indicate if the sensor was chosen for monitoring: 1 – Chosen 0 – Not Chosen	Byte	1	1
Accelerometer	Indicate if the sensor was chosen for monitoring: 1 – Chosen 0 – Not Chosen	Byte	1	2
Thermometer	Indicate if the sensor was chosen for monitoring: 1 – Chosen 0 – Not Chosen	Byte	1	3
Oximeter	Indicate if the sensor was chosen for monitoring: 1 – Chosen 0 – Not Chosen	Byte	1	4
Sum of the three first sensors	0 – ECG, Accelerometer and Thermometer not chosen 1 – One is chosen 2 – Two are chosen 3 – All chosen	Byte	1	5
Sum of Accelerometer and Oximeter	0 – Accelerometer and Oximeter not chosen 1 – Accelerometer or Oximeter is chosen 2 – Accelerometer and Oximeter are chosen	Byte	1	6
Sum of Thermometer and Oximeter	0 – Thermometer and Oximeter not chosen 1 – Thermometer or Oximeter is chosen 2 – Thermometer and Oximeter are chosen	Byte	1	7

Table 11: Message sent to the transmission module for the beginning of the session.

After the transmission module receives the message, he must send a confirmation message. This message indicates to the Data Center, if the message was successful by the transmission module. If the message wasn't successful the Data Center must send the message again.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 12: Confirmation message sent to the Data Center.

6.2.1.4. Data Transmission Message

When the transmission module has data to send, a message is composed, with the header with the number two. This message has full packet of data. A full packet of data is showed in table 13, without count the header. A message, sent to the Data Center without a full packet, is not viable. The six first bytes are for the temporal information and the straight away bytes of the packet are for the data information. If a packet is split, the message, when received by the Data Center, has an unknown format and the Data Center is not capable of work the message.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Temporal Information	Field with information about the instant of the data acquisition	Byte	6	1
ECG Data	Field with ECG data	Byte	200	7
Accelerometer Data	Field with Accelerometer data	Byte	6	207
Thermometer Data	Field with Thermometer data	Byte	2	213
Oximeter Data	Field with Oximeter data	Byte	N (N1+N2)	215

Table 13: Message to the Data Center with full packets of data.

Field	Description	Type	Size	Start Position
Year	Year of the data acquisition (only the two first digits) Range of values: [0…99]	Byte	1	1
Month	Moth of the data acquisition Range of values: [1…12]	Byte	1	2
Day	Day of the data acquisition Range of values: [1…31]	Byte	1	3
Hour	Hour of the data acquisition Range of values: [0…23]	Byte	1	4
Minute	Minute of the data acquisition Range of values: [0…59]	Byte	1	5
Second	Second of the data acquisition Range of values: [0…59]	Byte	1	6

Table 14: Temporal Information read from the RTC.

Field	Description	Type	Size	Start Position
Accelerometer – X-Axis	Data acquisition at the x-axis of the accelerometer	Byte	2	207
Accelerometer – Y-Axis	Data acquisition at the y-axis of the accelerometer	Byte	2	209
Accelerometer – Z-Axis	Data acquisition at the z-axis of the accelerometer	Byte	2	211

Table 15: Data acquisition in the accelerometer.

The size of the oximeter data is unknown because the sensor wasn't chosen. Therefore, two variables remains, N1 and N2. N1 is the SpO_2 data and N2 is the heart rate.

Field	Description	Type	Size	Start Position
SpO_2 reading	SpO_2 reading at the oximeter Range of values: [0…100]	Byte	N1	215
Heart Rate reading	Heart Rate reading at the oximeter	Byte	N2	215+N1

Table 16: Temporal Information read from the RTC.

When the Data Center receives the data message, he sends a confirmation message to the transmission module. If the received message has only full packets, the confirmation message has a byte with value 1. Case one of the packets is not a full packet, the byte, of the confirmation message, has the value 0 and the transmission message will send, again, the message.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 17: Confirmation message sent to the Transmission Module.

6.2.1.5. Session Finish Message

The healthcare provider is the responsible by the session begin. Therefore, he has the responsibility of end the session. When this option is selected, the Data Center sends a message for the transmission module (see table 18). The message header has the value 3.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0

Table 18: Message with information for the end of the session.

The transmission module receives the message and a session process of finishing start. The transmission module ignores new data message, he sends to the acquisition module an order to finish the data acquisition and all the others processes. When a confirmation message arrives, from the acquisition module, he sends, too, a confirmation message to the Data Center.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 19: Confirmation message sent to the Data Center.

6.2.1.6. Error Message

This type of message is sent by the transmission module to the Data Center to report a non expected event. The header has the identification number 5. During the session, the normal function of the system can be interrupted and an error occurs. Several causes can be the source of the problem and they are showed in table 21. Some of the causes are the end of communication between the transmission module and the acquisition module, the data memory of the transmission module is full or the loss of data in the acquisition module.

Field	Description	Type	Size	Start Position
Header	Header of the message, 6	Byte	1	0
Error type	Error information is in table 21	Byte	1	1

Table 20: Error message to the Data Center.

Error Code	Description
0x01	The 0x01 error code tells to the Data Center that the transmission module can't establish a new contact with the acquisition module.
0x02	The 0x02 error code tells to the Data Center at least one of the acquisition modules not sent a message with the connected sensors.
0x03	The 0x03 error code tells to the Data Center at least one of the acquisition modules not responded to the request message of data acquisition.
0x04	The 0x04 error code tells to the Data Center that the data memory of the transmission module has been full.
0x05	The 0x05 error code tells to the Data Center that the data memory of the acquisition module has been full and some data were lost.
0x06	The 0x06 error code tells to the Data Center at least one of the acquisition modules not responded to the request message to finish the data acquisition.

Table 21 Different types of errors.

The Data Center, after receives the error message, sends a confirmation message to the transmission module.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 22: Confirmation message sent to the Transmission Module.

6.2.2. Transmission Module ⇔ Acquisition Module

These two modules have two ways of communication, both wireless. They use Bluetooth or Zigbee technology as discussed early. Next, it is discussed how the communications, between these modules, take place.

6.2.2.1. Header

All the messages must have a header. The header, for this situation, is a single byte and is at the top of the message. This byte carries the information about the type of message received. How it is possible watch, in the table 23, the first identification number, in this header, is one. Therefore, the header can carries 255 different messages.

Field	Description	Type	Size	Start Position
Type of Message	This field identify the message Range of values: [1…255]	Byte	1	0

Table 23: Header of the messages.

6.2.2.2. Information Request about Connected Sensors

The first task made by the acquisition module, when power-up, is to connect to the transmission module network. If successful, both devices are capable of exchange messages. Transmission module's first message, to the acquisition module, is an information request about the connected sensors (see table 24). The header message has the identification number 1.

Field	Description	Type	Size	Start Position
Type of Message	Header of the message, see table 6	Byte	1	0

Table 24: Information request about the connected sensors.

At the moment of the request, the acquisition module knows, already, what sensors have connected. Therefore, when the request message arrives, it is only necessary put the information in the response message and use the same algorithm used in the previous communication protocol.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
ECG	Indicate if the sensor was chosen for monitoring: 1 – Connected 0 – Not Connected	Byte	1	1
Accelerometer	Indicate if the sensor was chosen for monitoring: 1 – Connected 0 – Not Connected	Byte	1	2
Thermometer	Indicate if the sensor was chosen for monitoring: 1 – Connected 0 – Not Connected	Byte	1	3

Oximeter	Indicate if the sensor was chosen for monitoring: 1 – Connected 0 – Not Connected	Byte	1	4
Sum of the three first sensors	0 – ECG, Accelerometer and Thermometer not chosen 1 – One is Connected 2 – Two are Connected 3 – All Connected	Byte	1	5
Sum of Accelerometer and Oximeter	0 – Accelerometer and Oximeter not Connected 1 – Accelerometer or Oximeter is Connected 2 – Accelerometer and Oximeter are Connected	Byte	1	6
Sum of Thermometer and Oximeter	0 – Thermometer and Oximeter not Connected 1 – Thermometer or Oximeter is Connected 2 – Thermometer and Oximeter are Connected	Byte	1	7

Table 25: Message sent to the transmission module with the information about the connected sensors.

6.2.2.3. Data Acquisition Request Message

After the transmission module receives the message with information about the connected sensors, he sends, immediately, another message to begin the data acquisition. The message, only with the header, is identified by the number 2.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0

Table 26: Data acquisition request message.

When the acquisition module receives the message, the data acquisition begins, in the detected sensors, and a confirmation message is sent to the transmission module.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 27: Confirmation message sent to the Transmission Module.

6.2.2.4. Lost Data Message

For an efficient communication between both devices, they must be a short distance. If by any reason the communications end, the acquisition starts to store the data in his local data memory. If the data memory reach the maximum capacity a flag is set. When both devices are, again, in the same network, the acquisition module sends a lost data message to the transmission module (see table 28). The message is identified by the number 3 in the header.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0

Table 28: Lost data message.

The transmission module receives the message and answers, sent a confirmation message.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 29: Confirmation message sent to the Acquisition Module.

6.2.2.5. Data Transmission Module

When the acquisition module has data to send, a message is composed, with the header with the number 4. This message has full packet of data. A full packet of data is showed in table 30, without count the header. The six first bytes are for the temporal information and the straight away bytes of the packet are for the data information.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Temporal Information	Field with information about the instant of the data acquisition	Byte	6	1
ECG Data	Field with ECG data	Byte	200	7
Accelerometer Data	Field with Accelerometer data	Byte	6	207
Thermometer Data	Field with Thermometer data	Byte	2	213
Oximeter Data	Field with Oximeter data	Byte	N (N1+N2)	215

Table 30: Message to the Transmission Module with full packets of data.

The size of the oximeter data is unknown because the sensor wasn't chosen. Therefore, two variables remains, N1 and N2. N1 is the SpO_2 data and N2 is the heart rate as it is possible to see in table 33.

Field	Description	Type	Size	Start Position
Year	Year of the data acquisition (only the two first digits) Range of values: [0…99]	Byte	1	1
Month	Moth of the data acquisition Range of values: [1…12]	Byte	1	2
Day	Day of the data acquisition Range of values: [1…31]	Byte	1	3
Hour	Hour of the data acquisition Range of values: [0…23]	Byte	1	4
Minute	Minute of the data acquisition Range of values: [0…59]	Byte	1	5
Second	Second of the data acquisition Range of values: [0…59]	Byte	1	6

Table 31: Temporal Information read from the RTC.

Field	Description	Type	Size	Start Position
Accelerometer – X-Axis	Data acquisition at the x-axis of the accelerometer	Byte	2	207
Accelerometer – Y-Axis	Data acquisition at the y-axis of the accelerometer	Byte	2	209
Accelerometer – Z-Axis	Data acquisition at the z-axis of the accelerometer	Byte	2	211

Table 32: Data acquisition in the accelerometer.

Field	Description	Type	Size	Start Position
SpO_2 reading	SpO_2 reading at the oximeter Range of values: [0…100]	Byte	N1	215
Heart Rate reading	Heart Rate reading at the oximeter	Byte	N2	215+N1

Table 33: Temporal Information read from the RTC.

When the Transmission Module receives the data message, he sends a confirmation message to the transmission module. If the received message has only full packets, the confirmation message has a byte with value 1. Case one of the packets is not a full packet, the byte, of the confirmation message, has the value 0 and the transmission message will send, again, the message.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 34: Confirmation message sent to the Acquisition Module.

6.2.2.6. Session Finish Message

When the transmission module receives a message to end the data acquisition, he must send the same message to the acquisition module (see table 35). The message header has the value 5.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0

Table 35: Message with information for the end of the session.

When the acquisition module receives the message a confirmation message is sent to the transmission module after all the processes stop.

Field	Description	Type	Size	Start Position
Header	Header of the message, see table 6	Byte	1	0
Response	Indicate if the message was successful: 1 – Successful 0 – Not Successful	Byte	1	1

Table 36: Confirmation message sent to the Transmission Module.

6.3. Flowcharts

After establish the rules for the communications between the Data Center and the Transmission Module and between the Transmission Module and the Acquisition Module, it is necessary understand how each machine will go work the information in his inner system. Therefore, it is necessary develop flowcharts for each machine, transmission and acquisition modules, to prevent all the possible situations that the machine will must resolve.

Once the system work with request-confirmation message, it is necessary understand that when a message is sent, a confirmation message is waited by who send the request message. Therefore, there is a timeout, where the device, that sends the request message, waits for the confirmation message and sends up to N request messages. Passed this timeout, if none confirmation message arrives an error occurs.

6.3.1. Transmission Module

The transmission module must be capable of manage all the “cross-fire” of information that exist with the Data Center and the Acquisition Module. In this section will be showed the steps followed by the module.

6.3.1.1. Power-up

When the healthcare provider power-up the transmission module, several events take place in the program. First, it is necessary change the configuration bits for the right needs. The configuration bits allow, each user, to customize certain aspects of the device to the needs of the application. The state of these bits determines the working modes of the device. After this configuration, it is not possible change the values of the configuration bits, during normal device operation.

When the program ends this first task, and before the program enter in the main function (see figure 20), is necessary create some variables. These variables will be useful during the device operation.

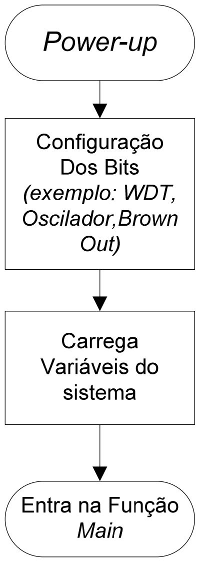

Figure 20: First tasks executed by the program when the machine is power-up.

As soon as the tasks, talk in the previous paragraph, are completed, the program enters in the *main* function (see figure 21). For a good programming, it is necessary block the interruptions, immediately. After that, it must be programmed the registers of the hardware modules (see figure 22). This will go prevent unexpected behaviors in the system. Since the Wi-Fi or GPRS modem and the Bluetooth or Zigbee modem are connected to the PIC, the Microchip's microcontroller, by the EUSART module, the interruptions, for this module, must be enabled. Next, the system will go enter in an infinite *while cycle*.

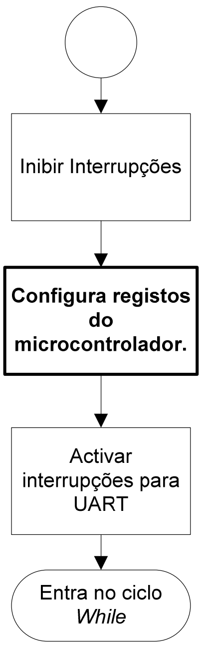

Figure 21: Inside the *main* function, the programs make more configurations before enter in the *while cycle*.

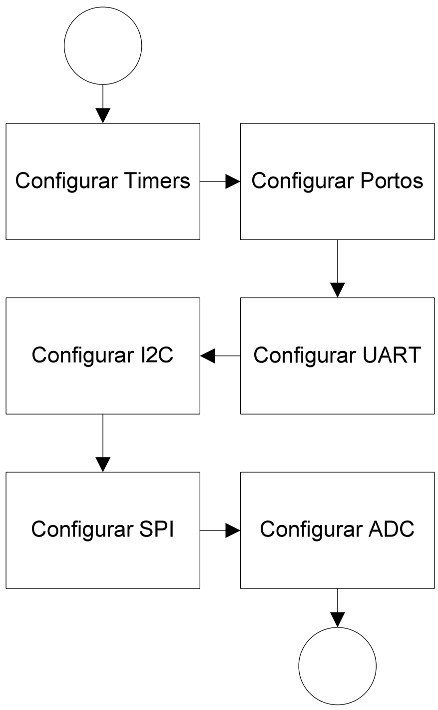

Figure 22: Configuration of the microcontroller's registers.

The *while cycle* is a states machine (see figure 23), where the main program runs. He contains command interpreter, a control of the active process and a *switch* statement.

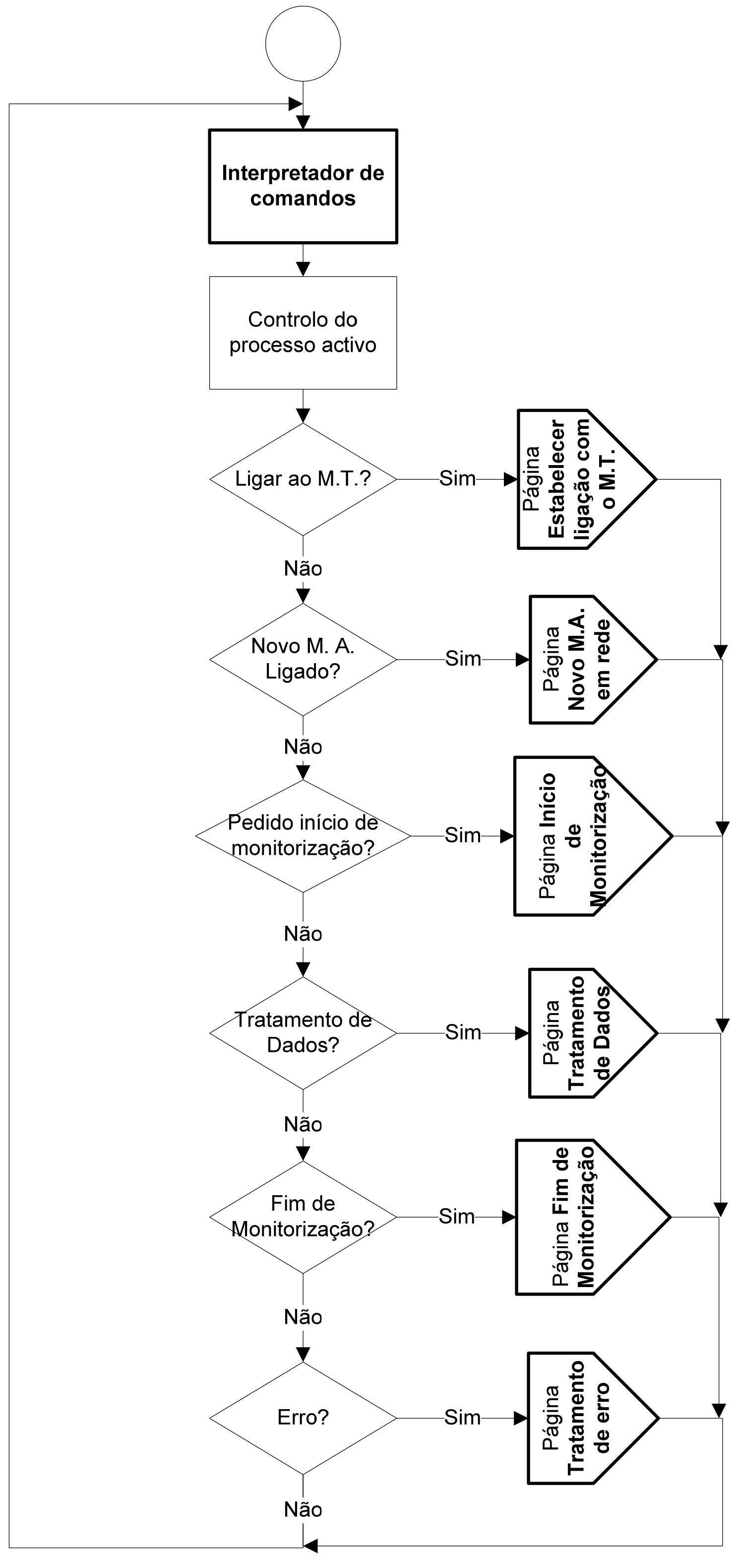

Figure 23: Skeleton of the program running inside the *while cycle*.

6.3.1.2. Message Receiving

An upcoming message induces an interruption in the EUSART module of the PIC. The PIC will receive the entire message, read and build an internal command. If this command is a valid command, a flag will be set (see figure 24). If is not a valid command the message is ignored.

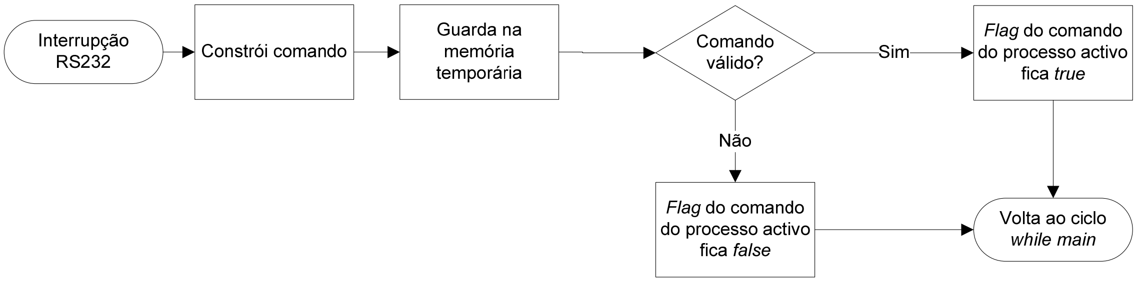

Figure 24: Message receiving and command construction.

Since the flag is set, the command interpreter must clear the flag and transfers the internal command for the control of the active process (see figure 25). Only after this process be finished, it is possible, to the system, execute one of the *case* of the states machines.

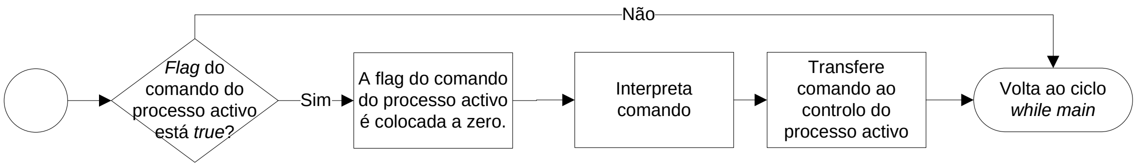

Figure 25: Control of the active process.

The first task, of the states machine, is to connect to the Data Center. The Transmission Module tries, first, a connection with the USB cable. The idea of first tries to connect with a wire technology is to minimize the power consumption of the device. If this device is not linked, by USB, the transmission module will go connect wireless to the Data Center (see figure 26).

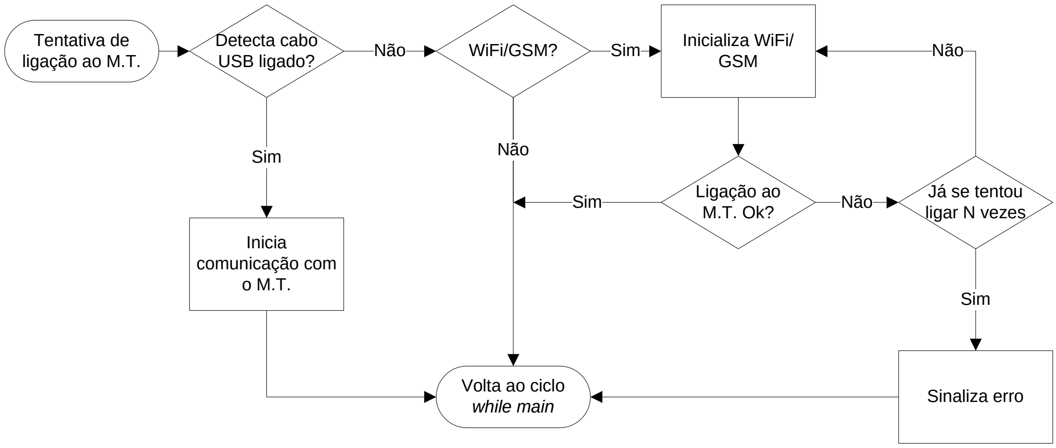

Figure 26: Process to the transmission tries to connect to the Data Center.

After power-up the transmission module, the healthcare provider will go power-up the acquisition modules. When one of them enters in the transmission module's network, "warning" message arrives to the PIC and, if it is not already registered, the acquisition module will be registered in the configuration memory (see figure 27).

Figure 27: Process of registration of a new acquisition module.

6.3.1.3. Monitoring Session Beginning

When the Data Center sends a message to begin a monitoring session, the transmission module must send, first, a message to the acquisition modules requesting information about the connected sensors. If, at least, one of the acquisition modules don't respond or all of them respond but the information doesn't match with the information sends by the Data Center an error message is sent to the Data Center. If everything is right, the transmission module sends another message to the acquisition modules to start the data acquisition (see figure 28).

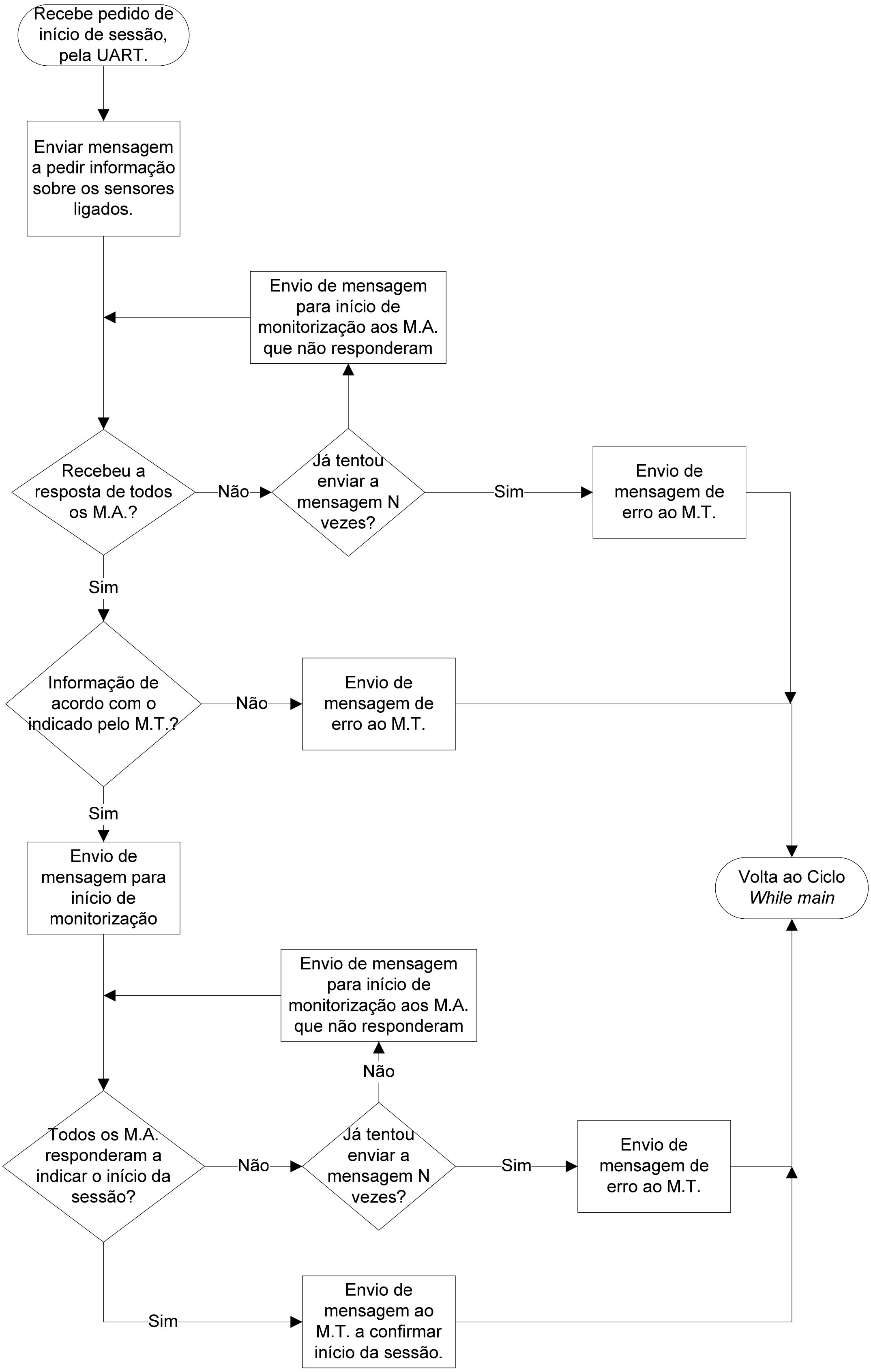

Figure 28: Monitoring session beginning.

6.3.1.4. Data Treatment

After the beginning of the data acquisition, by the acquisition modules, the transmission module will be checking if any data arrive. If:

- New data came from the acquisition module, the transmission module analyzes the message. If:
  - It is an error message, report lost data, he sends a report message to the Data Center and wait the confirmation message;
  - It is a message with acquired data, another decision must be done. When the healthcare provider chooses between live session and offline session a critical decision was made. If the healthcare provider chooses an offline session the data are stored in the local data memory. When the local data memory is full a message will be sent to the Data Center. By the other hand, if it was chosen a live session, the data will be sent, immediately. However, before that happens a reading in the local memory must be done. If there are data stored, them the new data is stored and the older data are sent first. This process keeps until all the data are, successful, sent. Case one of the messages wasn't, successful, sent an error sign is set in the transmission module and the previous reading is canceled.
- There aren't new data, the system checks if there are data to send in the data memory. If no, nothing is done. If yes, the data are read, beginning in the older data, and sent to the Data Center (see figure 29).

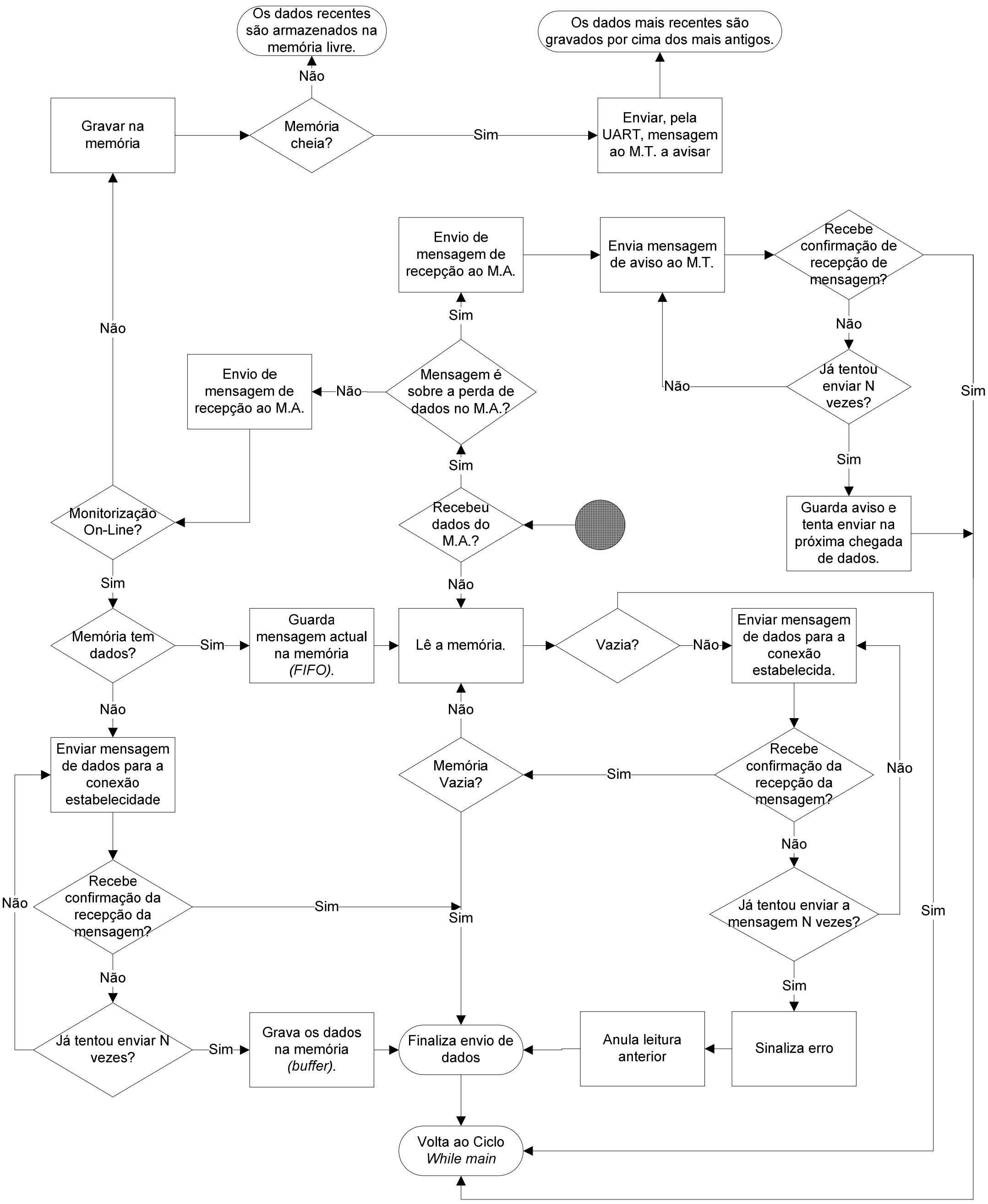

Figure 29: Data Treatment at the Transmission Module.

6.3.1.5. *Session Finish*

When the transmission module receives the message, a couple of actions take place. No more data, from the acquisition modules, are accepted and an end session message is sent to the acquisition modules. If all the acquisition modules send a confirmation message, the transmission module sends a confirmation message for the Data Center (see figure 30).

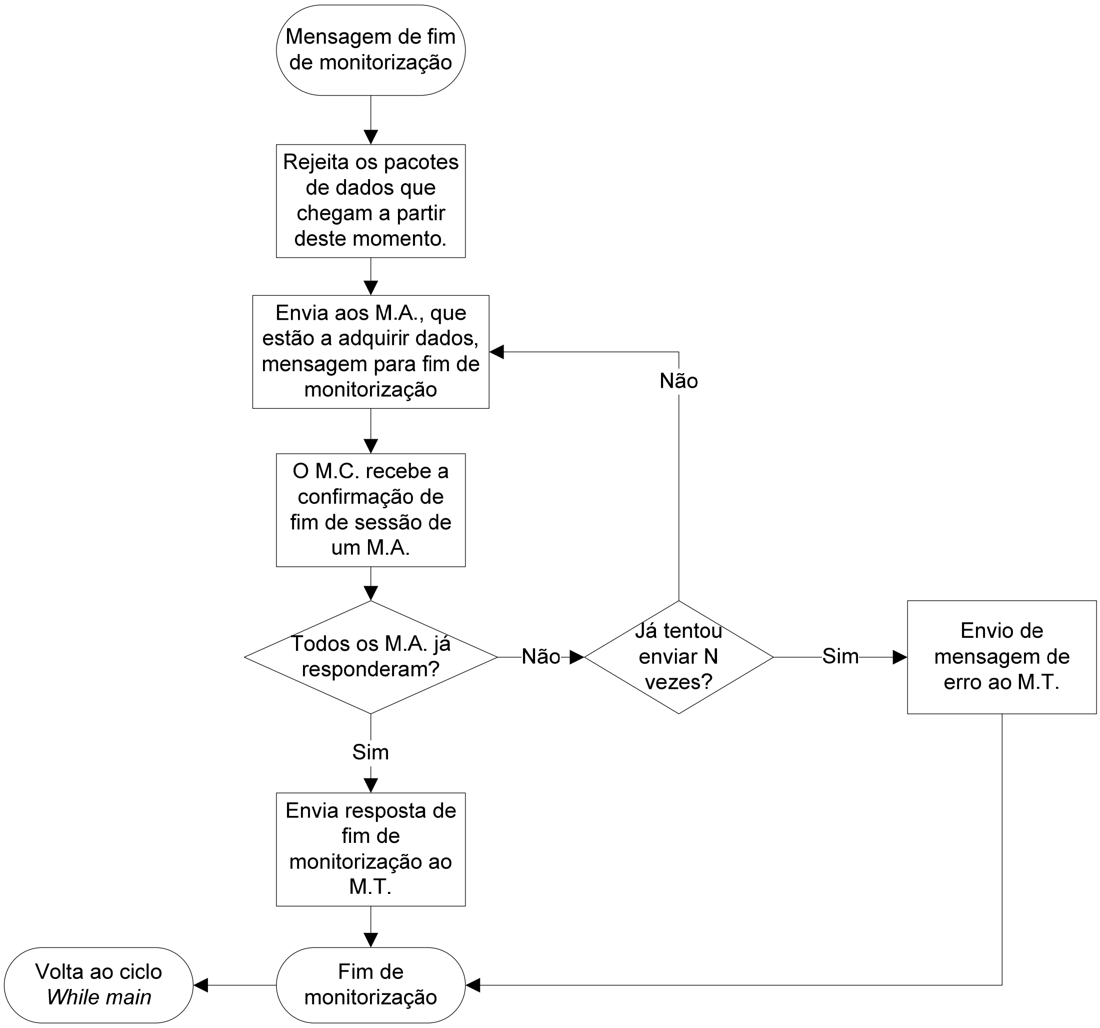

Figure 30: Session finish request to the Transmission Module.

6.3.1.6. Error Treatment

In the middle of the process, errors can occur. If the error occurs, the system must be capable of fix the problem, an error treatment must be done. The solution to fix the problem is the healthcare provider push an existing button, in the transmission module. When the button is pressed, the system is capable to return to the previous logical function.

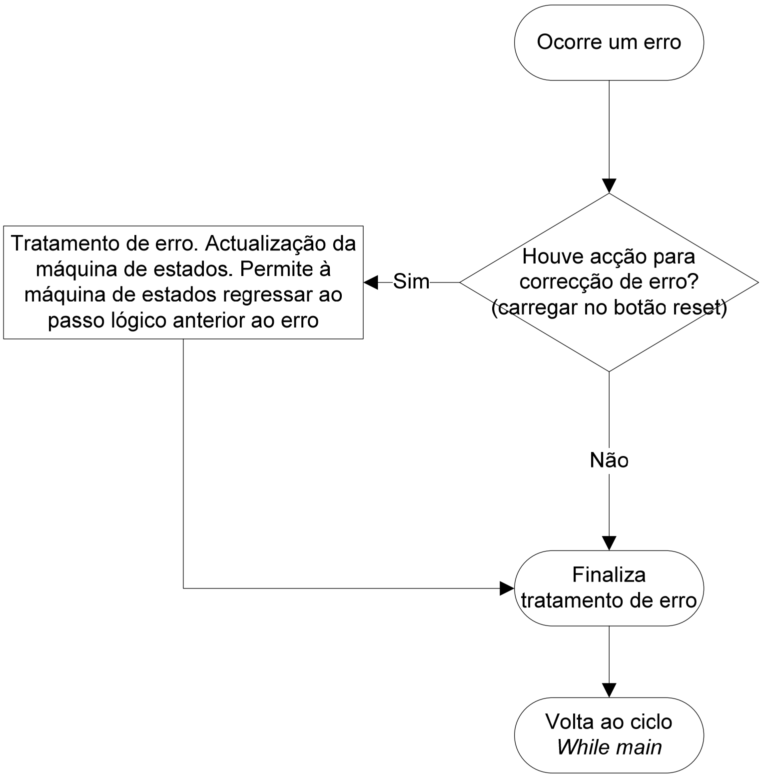

Figure 31: Error treatment made by the transmission module when the healthcare provider push the button.

6.3.2. Acquisition Module

The acquisition module is the device with the primary task of data acquisition. However, the acquisition module only starts the acquisition when an order arrives from the transmission module. The acquisition takes place only with the connected sensors. This module has some similar functionalities with the transmission module but, also, particular functionalities. Next, these functionalities are discussed in detail.

6.3.2.1. Power-up

After power-up the transmission module the health care provider must power-up the acquisition modules. When the healthcare provider power-up the acquisition module, several events take place in the program. First, it is necessary change the configuration bits for the right needs. The configuration bits allow, each user, to customize certain aspects of the device to the needs of the application. The state of these bits determines the working modes of the device. After this configuration, it is not possible change the values of the configuration bits, during normal device operation.

When the program ends this first task, and before the program enter in the main function (see figure 32), is necessary create some variables. These variables will be useful during the device operation.

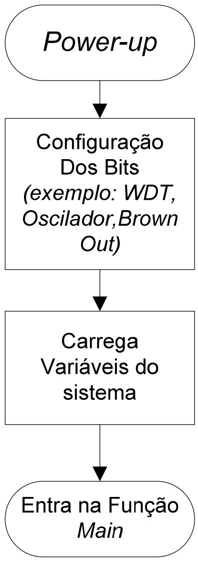

Figure 32: First tasks executed by the program when the machine is power-up.

As soon as the tasks, talk in the previous paragraph, are completed, the program enters in the *main* function (see figure 33). For a good programming, it is necessary block the interruptions, immediately. After that, it must be programmed the registers of the hardware modules (see figure 34). This will go prevent unexpected behaviors in the system. Since the Bluetooth or Zigbee modem are connected to the PIC, the Microchip's microcontroller, by the EUSART module, the interruptions, for this module, must be enabled. To spare time, the acquisition module will go find which sensors are connected and which aren't. Next, the system will go enter in an infinite *while cycle*.

Figure 33: Inside the *main* function, the program makes more configurations before enter in the *while cycle*.

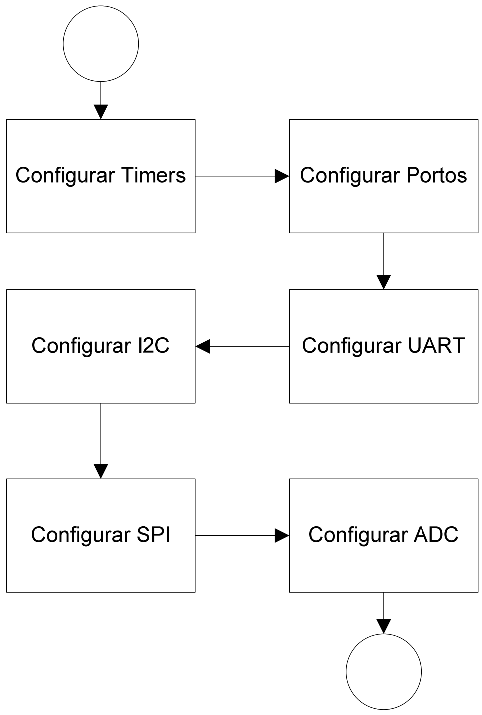

Figure 34: Configuration of the microcontroller's registers.

After the system complete these initial tasks, the program enter in the infinite *while cycle*. Here, like in the transmission module, is used a states machine where the main functions are executed. Into the *while cycle* there is a command interpreter a control of the active process and a *switch* statement (see figure 35).

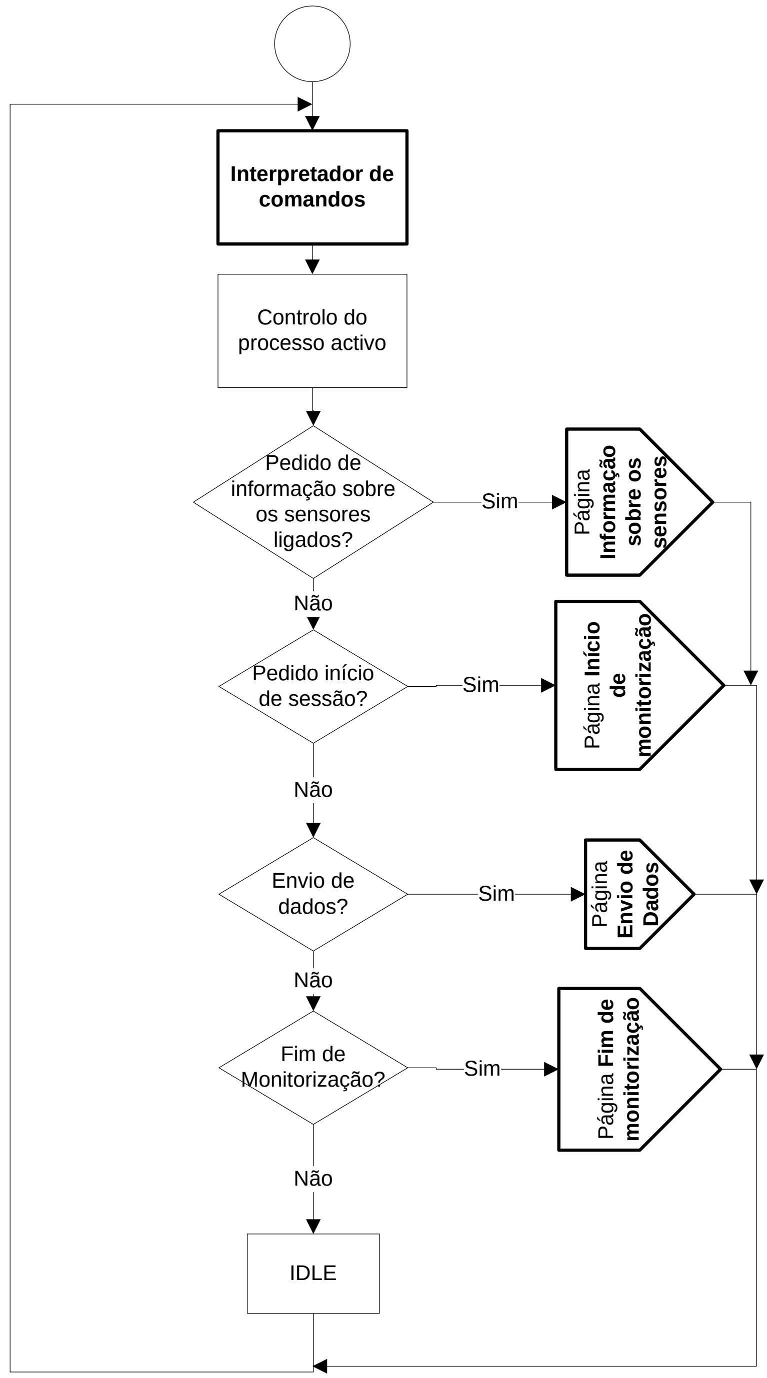

Figure 35: Skeleton of the program running inside the *while cycle*.

6.3.2.2. Message Receiving

The message receiving is a basic process in the system. Therefore, the concept used here is the same used in the transmission module. The upcoming message induces an interruption in the EUSART module of the PIC. When the reception is complete, the message is interpreted and an internal command is build. A flag will be set if the internal command is a valid one (see figure 36).

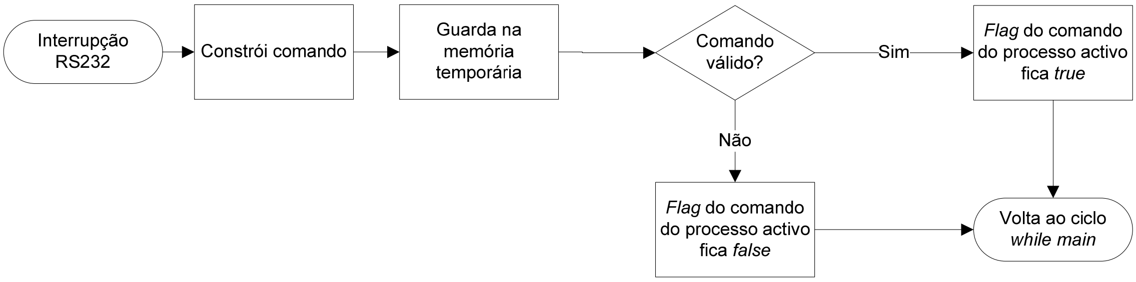

Figure 36: Message receiving and command construction.

Since the flag is set, the command interpreter must clear the flag and transfers the internal command for the control of the active process (see figure 37). Only after this process be finished, it is possible, to the system, execute one of the *case* of the states machines.

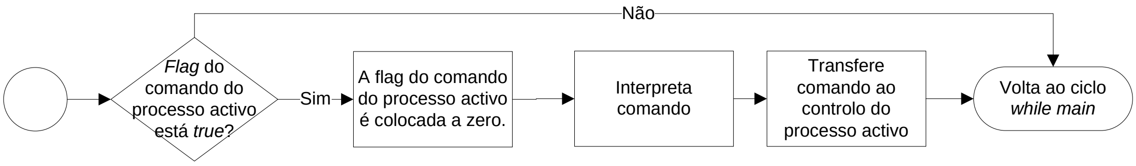

Figure 37: Control of the active process.

6.3.2.3. Sensors Information request

The first message, from the transmission module, will be a request to get information about the connected sensors in the acquisition module. Since the information is already taken, the system only must put the information in a message and send to the transmission module (see figure 38).

Figure 38: Acquisition response to the sensors information request.

6.3.2.4. *Monitoring Session Beginning*

After reading the information about the sensors, the acquisition module will receive a message to start the data acquisition. When this happen the *timers*, PIC's modules, are configured and the interruptions are set. The acquisition take place and a confirmation message is sent to the transmission module (see figure 39).

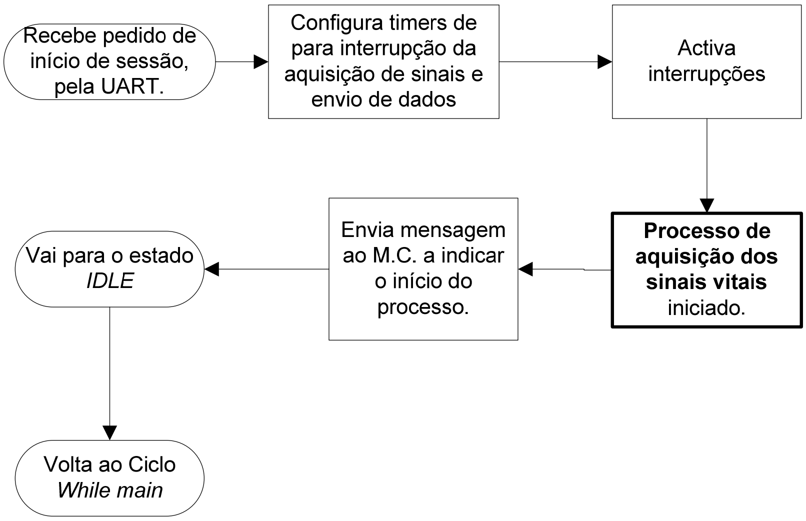

Figure 39: Monitoring session beginning process.

6.3.2.5. *Data Acquisition Process*

The data acquisition is under control of a *timer* and an interrupt event. The interruption takes place in a precision frequency. When the interruption occurs a global counter is incremented one unit and if an ECG is connected, an ECG acquisition takes place.

The ECH is the sensor with the highest acquisition frequency. Therefore, the interruption frequency is ruled by the "quality" of the ECG pretended. A good frequency for the data acquisition, without lose much information (the physician can look to the graphic and take some important conclusions, as example if the QRS complex or the T wave has a normal appearance), is 100Hz. Therefore, the interrupt frequency is 100Hz and at each interruption a data acquisition is taken if the ECG was connected to the acquisition module, before the power-up. The others sensors have a lower acquisition frequency. Like the ECG frequency, the frequency for these sensors was chosen with the supervisors. Once the vital signs, acquired in these sensors, have little changes over the time, the acquisition frequency can be low. With the objective of save energy, the data must be sent, in packets, to the transmission module. A packet will have one second of data. Therefore, an acquisition, with all the sensors connected, will have one packet with temporal information, 100 data from the ECG and one datum from each of the other sensors.

When the global counter reach 100, the others sensors, connected to the acquisition module, are sampled, the counter return to zero, the data are indexed to the

RTC information, with temporal information, and the packet is stored in the local data memory. If the local data memory is already full, the packet must be stored in the place where the data are the oldest and a flag must be set (see figure 40).

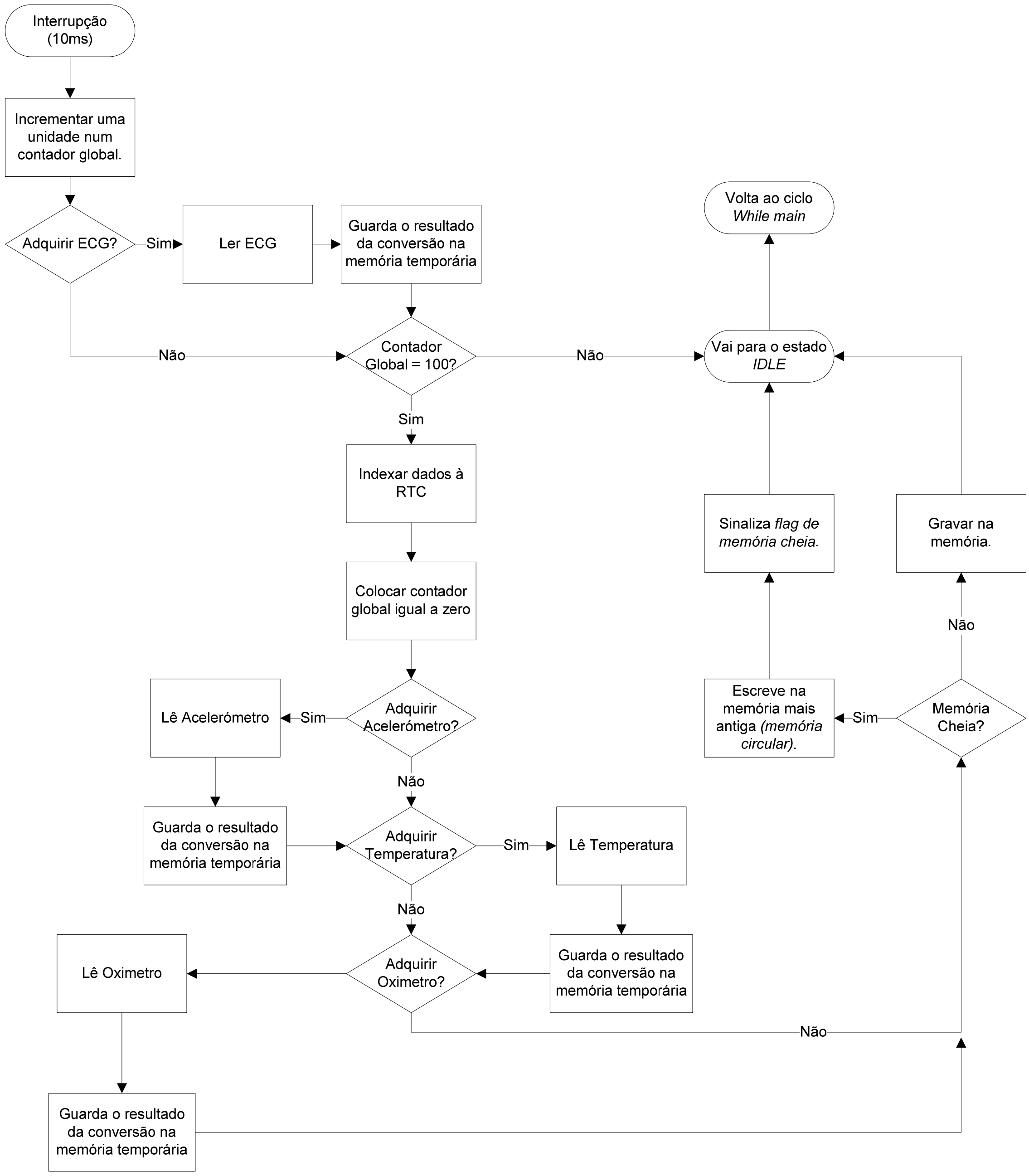

Figure 40: Process of data acquisition.

6.3.2.6. Sending Message

The process to send data depends of an interruption. The frequency for this interruption is an open matter but probably between 1 and 8 seconds. When the interruption occurs, the system will check the status of the flag used in the local data memory. If set, an error message is sent to the transmission module reporting lost data. If the confirmation message arrives the flag is clear. Only now a data message can be sent to the transmission module. The local data memory is read, the oldest data first, and a message is sent (with full packets) to the transmission module. If no confirmation message arrives the read is ignored and the firmware returns to the main program (see figure 41).

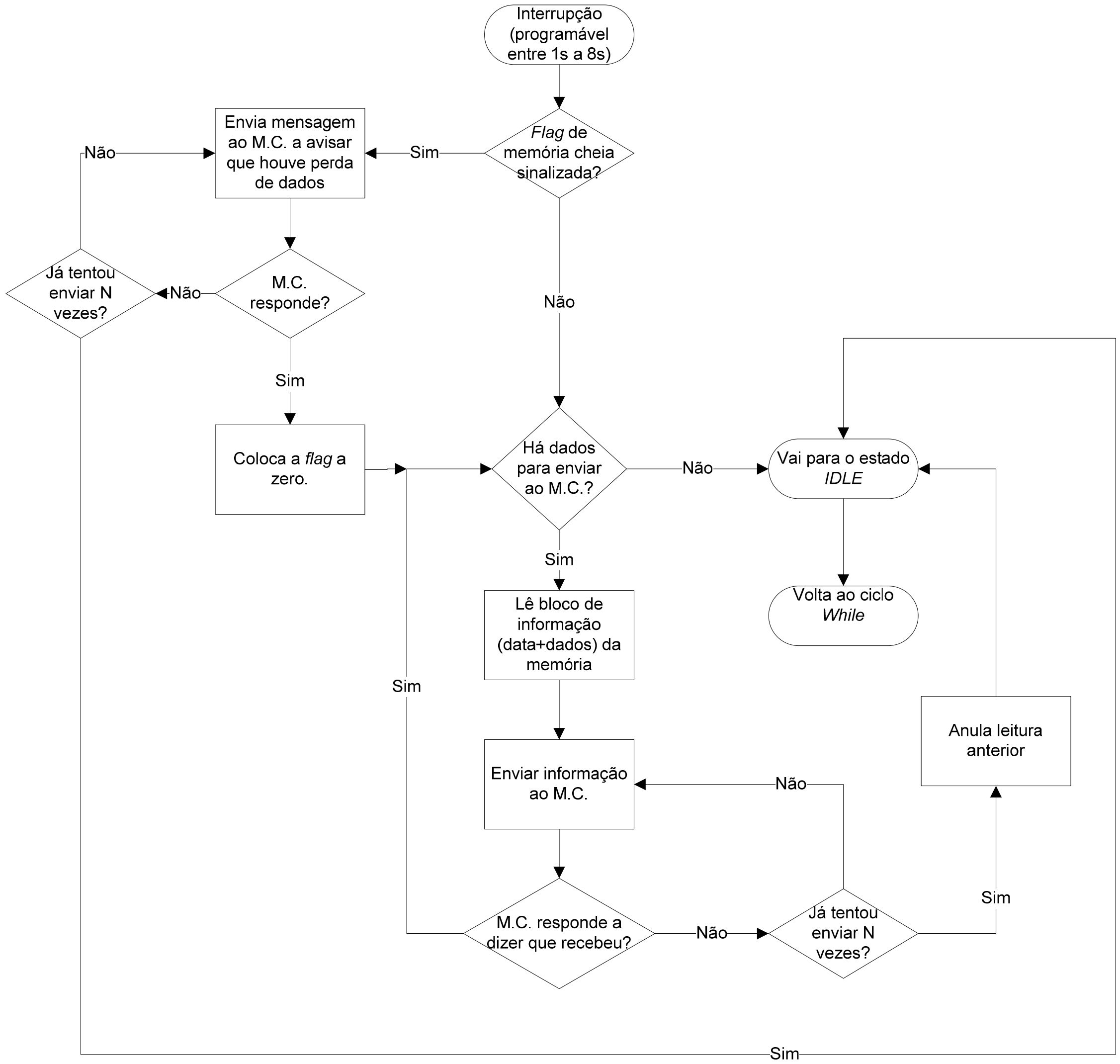

Figure 41: Process taken to send the data acquired.

6.3.2.7. Session Finish

When the transmission module receives a message from the transmission to end the session, the interruptions, in the system, came to an end. Only the interruptions, for the EUSART module, remain. Finally, a confirmation message is sent to the transmission module (see figure 42).

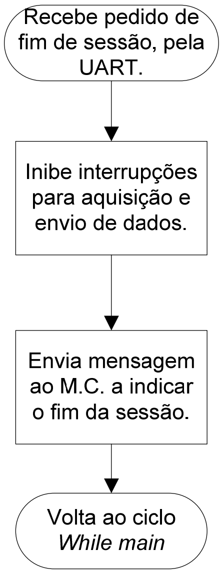

Figure 42: Session finish request to the Acquisition Module.

Chapter 7

7. Conclusion

The project Portable System for Vital Signs Measurement was developed through the academic year of 2006/2007. During this time, the students had to work in the individual and group tasks. The most important group task, made by the students, was the project's documentation, Vision and Objectives and Requirements Analysis. With the documentation done, it is possible to identify the needs of the healthcare provider to survey a patient, the economic reasons and what systems exist at the present day, the state-of-the-art. Another important feature was the correct choice of the communications since the solution must be cheap but must support a good dataflow.

The Data Center is the interface of the system with the healthcare provider. Therefore, the architecture of the acquisition and transmission module was, only, defined after the Data Center Skin. The definition of the Skin allows know better what the healthcare provider wants, the options and how the data are seen. The communication protocols and the flowcharts allow identify a set of tools to the systems work well. The communication protocols will go help the machines to understand what one machine wants to say to the other. Without these protocols, the exchange of information between the machines wasn't possible. The flowcharts are the representation of the internal function of the machines. In the flowcharts, all the situations must be prevented.

However, the final objective wasn't achieved. The development of the firmware to run in the acquisition and transmission modules never started. The delay, in the definition of a convergent strategy to the project, was too long and, in the end, it wasn't possible make the program. With the objective of check the acquisition and transmission modules' hardware a test code was developed but he wasn't finish and, therefore, he wasn't presented here.

Appendix

The communication protocol uses an algorithm for ensure that the information carried by the message is not corrupted. This algorithm is used for analyse the quality of messages that have information about the sensors. Next, it is made a demonstration to show that the algorithm carried only a single result. So, when the transmission module receive the message, it is possible to know, exactly, what sensors are chosen/connected and what aren't.

Three bytes are used to make this algorithm. The first byte is the sum of the 3 first sensors (ECG + accelerometer + thermometer) (in the message if a sensor is chosen/connected, the byte has the value one, if not the byte has the value zero). The second byte is the sum of the second and fourth sensors (accelerometer + Oximeter). The third, and final, byte is the sum of the third and fourth sensors (thermometer + Oximeter).

If it is defined:

- S1 ⇔ ECG;
- S2 ⇔ Accelerometer;
- S3 ⇔ Thermometer;
- S4 ⇔ Oximeter;
- A = S1 + S2 + S3;
- B = S2 + S4;
- C = S3 + S4.

Set A can have 4 different values, 0, 1, 2 or 3, set B and C can have 3 different values, 0, 1 or 2. With the objective of prove, for this algorithm, that the solution is single it is necessary, first, know how many sensors combinations are possible. In a message, it is possible to have 0 to 4 sensors selected. So, it is necessary calculate the sensors combinations for these 5 possibilities. Since the order doesn't matter, they will be calculated the possible combinations, ${}^{n}C_{p} = \frac{n!}{p!(n-p)!}$, where n represent all the sensors, 4, and p represent the number of sensors chosen.

For:

- $p = 0 \Longrightarrow \quad {}^{4}C_{0} = \frac{4!}{0!(4-0)!} = 1;$
- $p = 1 \Longrightarrow \quad {}^{4}C_{1} = \frac{4!}{1!(4-1)!} = 4;$
- $p = 2 \Longrightarrow \quad {}^{4}C_{2} = \frac{4!}{2!(4-2)!} = 6;$
- $p = 3 \Longrightarrow \quad {}^{4}C_{3} = \frac{4!}{3!(4-3)!} = 4;$
- $p = 4 \Longrightarrow \quad {}^{4}C_{4} = \frac{4!}{4!(4-4)!} = 1.$

It is possible to know that the number of possibilities is 16, sum all the previous 5 results. Now, for each possibility (different p), it must be showed that only exist a single solution for each case.

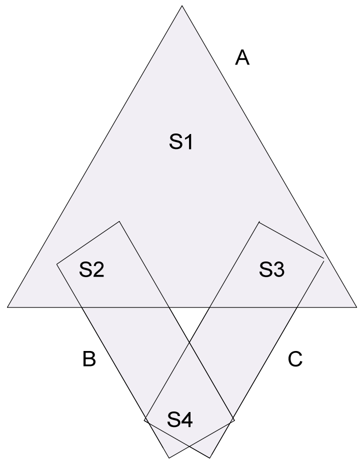

Figure 43: Set and subsets with the respective sensors.

Zero sensors selected:

In this case there is only a single situation. Set A, B and C must be equal to zero.

One sensor selected:

If $A = 0$ the sensor chosen is S4 because $A = S1 + S2 + S3 = 0$;

If $A = 1$:

- If $B = 0 \wedge C = 0$ the sensor chosen is S1 because $B \cup C = \{S2, S3, S4\}$;
- If $B = 1 \wedge C = 0$ the sensor chosen is S2 because $B \cap C = \{S2\}$, $C = S3 + S4 = 0$ and $B = S2 + S4 = 1 = S2$;
- If $B = 0 \wedge C = 1$ the sensor chosen is S3 because $B \cap C = \{S3\}$, $B = S2 + S4 = 0$ and $C = S3 + S4 = 1 = S3$.

Two sensors selected:

If $A = 1$:

- If $B = 1 \wedge C = 2$ the sensors chosen are S3 and S4 because $C = S3 + S4 = 2$;
- If $B = 2 \wedge C = 1$ the sensors chosen are S2 and S4 because $B = S2 + S4 = 2$;
- If $B = 1 \wedge C = 1$ the sensors chosen are S1 and S4 because $B = S2 + S4 = S4$ and $C = S3 + S4 = S4$.

If $A = 2$:

- If $B = 1 \wedge C = 1$ the sensors chosen are S2 and S3 because $B = S2 + S4 = S2$ and $C = S3 + S4 = S3$;
- If $B = 1 \wedge C = 0$ the sensors chosen are S1 and S2 because $C = S3 + S4 = 0$;

- If $B = 0 \land C = 1$ the sensors chosen are S1 and S3 because $B = S2 + S4 = 0$.

Three sensors selected:

If $A = 2$:

- If $B = 2 \land C = 2$ the sensors chosen are S2, S3 and S4 because $B \cup C = \{S2, S3, S4\}$;
- If $B = 2 \land C = 1$ the sensors chosen are S1, S2 and S4 because $B = S2 + S4 = 2$ and $C = S3 + S4 = S4$;
- If $B = 1 \land C = 2$ the sensors chosen are S1, S3 and S4 because $C = S3 + S4 = 2$ and $B = S2 + S4 = S4$.

If $A = 3$ the sensors chosen are S1, S2 and S3 because $A = S1 + S2 + S3 = 3$;

Four sensors selected:

When the four sensors are chosen there is a single case. Set A must be equal to 3, set B and set C must be equal to 2.

Acronyms

LED……………. Light Emitting Diode

NASA…………. National Aeronautics and Space Administration

CPOD………... Crew Physiologic Observation Device

SpO_2………….. Oxygen Saturation in the bloodstream

FSK……………. Frequency Shift Keying

ECG…………… Electrocardiogram

EMG…………… Electromyogram

GPS…………… Global Positioning System

BAN…………… Body Area Network

GPRS…………. General Packet Radio Service

UMTS…………. Universal Mobile Telecommunications System

MBU…………… Mobile Base Unit

PDA…………… Personal Digital Assistance

PC…………….. Personal Computer

GSM………….. Global System for Mobile Communications

PEF…………… Peak Expiratory Flow

Kbps………….. Kilobits per second

Mbps………….. Megabits per second

ISM…………….. Industrial, Scientific and Medical band

WPAN…………. Wireless Personal Area Network

INE…………….. Instituto Nacional de Estatística

UMIC………….. Agência para a Sociedade do Conhecimento

ICT…………….. Information and Communication Technologies

LAN……………. Local Area Network

USB……………. Universal Serial Bus

RTC……………. Real Time Clock

IMEI…………… International Mobile Equipment Identification

MAC address… Media Access Control address

EUSART……… Enhanced Universal Synchronous Receiver Transmitter

IDE…………….. Integrated Development Environment

CPU…………… Central Processing Unit

ADC…………… Analogical to Digital Converter

DAC…………… Digital to Analogical Converter

RAM…………… Random Access Memory

ROM…………… Read-Only Memory

I/O…………….. Input/output

RISC………….. Reduced Instruction Set Computer

CISC………….. Complex Instruction Set Computer

SNS…………… Serviço Nacional de Saúde

IDE……………. Integrated Development Environment

ID……………… Identification

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