Degree's Final Project

Bachelor's Degree in Industrial Technology Engineering

Development of a Python application for monitoring RF messages using one NRF24L01 board and a USB-MPSSE cable

REPORT

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Summary

The objective of this project is to build a python application to monitor radiofrequency (RF) packets on a personal computer (PC). In order to do this, a NRF24L01 board will be used together with a USB-MPSSE cable to connect the board with the PC. This system attempts to replicate a sniffer functionality, capable of receiving packets from different transmitters with very little information from their configuration. This functionality, which goes beyond regular packet reception, allows the user not only to catch messages from transmitters with little information of their configurations but also to provide message monitoring from devices with different configurations at the same time.

This report attempts to give the reader a progressive introduction to RF communications starting from a basic communication mode in which regular messages are sent and received throughout the NRF24L01 and ending with a far more complex mode where the application catches the packets just by knowing the first 3 bytes from their address, no matter how long it is and also without knowing the CRC length. Then it will not only extract the message from the unknown packet but also predict the transmitters configuration and configure the receiver accordingly to optimize the reception of the following packets.

None of these latter functionalities are provided by the NRF24L01 itself. Therefore, this project presents a software based enhancement of the NRF24L01 possibilities, extending these chip processing capabilities to the PC processor.

In addition, a deep insight into the Graphic User Interface creation is given coupled with the interaction of some basic libraries that have been adapted to meet these project necessities.

Two examples of these functionality extensions have been implemented in the application and are detailed in this report. These are: Fast file download and Focus.

Finally, this report explains the conversion of the python application into an executable file for Windows, meaning that this application can be executed in every Microsoft Windows OS without requiring neither python or any of its modules installation.

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Annexes

1. Glossary

DI/DO: Data In/Out.

C232HM-DDHSL-0: USB Hi-Speed – MPSSE Cable's reference.

CE: Chip enable.

CSN: Chip Select (active low).

GND: Ground.

GPIOL: General Purpose Input/Output.

GUI: Graphic User Interface.

JTAG: Joint Test Action Group.

MCU: Microcontroller Unit.

MISO: Master In Slave Out.

MOSI: Master Out Slave In.

MPSSE: Multi-Protocol Synchronous Serial Engine.

RF: Radio Frequency.

SCK/SK: Serial Clock.

SPI: Serial Peripheral Interface.

VCC: Collector to Collector Voltage.

CRC: Circuit redundancy check.

SAR: Specific energy absorption rate.

2. Introduction

This project arises from the necessity of the Electronic Engineering Department from ETSEIB – UPC to have a low cost device to monitor RF communications. This device permits to catch packets with different configurations and provide feedback in order to fix any problem that may occur. Moreover, this project can be used as a learning tool for the students to understand how the communication works and what is the roll of every part of the packet structure.

2.1. Objectives

Although there are some inevitable hardware items inherent to the project that need to be tackled, fundamentally, this is a software development based project. The main objective is to develop a GUI application which, together with a couple of low cost devices, can replicate the functionality of a RF sniffer. In order to achieve that goal, the project needs to get through several stages including:

- The development of a python library to access SPI hardware.
- The development of a python library to communicate with a nRF24L01 board, that means, being able to configure the chip as well as to send and receive data.
- The manual implementation of a "Promiscuous reception" mode, which provides the sniffer with the possibility of tracking several addresses at a time.
- Take profit of this "Promiscuous reception" and the *Enhanced Shockburst* packet to use the CRC in order to get the message with no more information from the transmitted packet than the first 3 bytes of the address and the working frequency.
- Upon these libraries, build a python GUI application which prevents the user from any contact with neither the python code nor the python terminal (that means, no programming notions required) as well as providing a windows .exe file so that the user can use this app in almost any computer.
- Keep record of the device configuration and all the packet transaction done in the last use of the application and save it in a text file.

2.2. Scope

This project does **not** contain a detailed explanation of all the characteristics of the hardware devices. As mentioned before, this is a software development based project. Therefore, only the necessary information to understand how the program works will be covered.

This project contains a detailed insight into programing procedures and the RF package communication.

2.3. Overview

This project consists in the development of GUI (Graphic User Interface) application to control a NRF24L01 board. This board is capable of both receiving and transmitting RF (Radiofrequency) packets from other boards and is connected to the PC via USB cable. The whole system will be named sniffer, which is able to catch and analyse packets sent by other NRF24L01 boards.

The application is divided in three different modes. Three different ways of configuring the board in order to obtain different functionalities. Their sequential development permits the following mode to soak up all the experience acquired in the previous one.

The first one is called Manual mode and it could be seen as an introduction to the NRF24L01 basic procedures such as changing registers and sending/receiving messages.

The second one, Multireceiving mode, is a previous stage before moving on to the complexity of the last mode. It allows the sniffer to receive packets from different addresses, which typically corresponds to different transmitters. Moreover, this mode gives information about the address from which every message comes from.

Up to this point, it can be easily noticed that it is all about changing registers. Nevertheless, the third mode, Automatic mode, takes this project into a whole new level of complexity where the NRF24L01 functionalities are insufficient and a few smart plays are needed so that the board can do the trick. The chief aim of this mode is to implement the so called “Promiscuous reading”, which means receiving packets without knowing the last bytes of the address. However, it was acknowledged that this mode did not deserve its name, since the user should still introduce some NRF24L01 parameters (apart from a partial address and the frequency) that made this mode not even close to being automatic. Not before acquiring a deep knowledge of the packet structure, a solution to this problem could be found. A glimmer of hope was delivered to this mode when the enormous potential of the CRC was discovered. The CRC is a one or two bytes' code, located at the very end of the packet, that is calculated over the whole packet. Although it could seem a minor element within the packet structure, it provided a lot of room for improvement allowing this mode to just give as parameters the first 3 bytes from the address (no matter its total length) and the working frequency in order to extract the message and important information about the transmitters configuration. It should be noted that the board is incapable of processing a packet in that way, therefore it has been configured to just store as much bytes as possible in its FIFO (First In First Out) after receiving the first 3 bytes from the address. This permitted catching packets and being able to process them (this is message, CRC length, PID and full address extraction) out of the NRF24L01 which gives the application free rein to work with that bunch of bits. Obviously, this enhancement of capabilities did not come at any cost. Reducing the address length results in more noise being captured which couple with a slower message extraction became a problem when sending large packets. Many measures were taken in that sense, such as the CRC calculation function optimization and a multithreading programming structure. Both actions increased considerably the processing speed. Not satisfied with that, two more functionalities were implemented taking the flexibility of an Automatic mode, and the processing speed of a standard packet reception. How this is achieved will be explained at length in this report.

It is also worth mentioning that great efforts have been devoted into GUI development in an attempt to stand out among the basic Window's window giving this app a personalised and professional outfit.

Finally, the reader can complement this report with an exhaustive documentation over all the classes and methods that this application contains which is available on the CD and in many links within this report. This documentation has been built with sphinx. Annex B provides screenshots regarding the first_level_class.py file as an example.

3. Hardware

There are 3 devices involving this project which allow the design of a radio system through which communication with other devices can be established. These are the followings:

- **The nRF24L01+ Single Chip 2.4GHz Transceiver (NRF24L01 board) [1]**
- **A USB Hi-Speed – MPSSE Cable (C232HM-DDHSL-0) [2]**
- **A personal computer**

3.1. nRF24L01+ board

This NRF24L01 board is able to both transmit and receive RF data. It simply needs an MCU to start working. The communication between the computer and the nRF24L01 board is established through a Serial Peripheral interface (SPI). This chip is compatible with Enhanced ShockBurst, which is, according to the datasheet [1], *“a packet based data link layer that features automatic packet assembly and timing, automatic acknowledgement and retransmissions of packets”*. All the content the reader needs to know in order to understand this project is fully covered in the datasheet mentioned before.

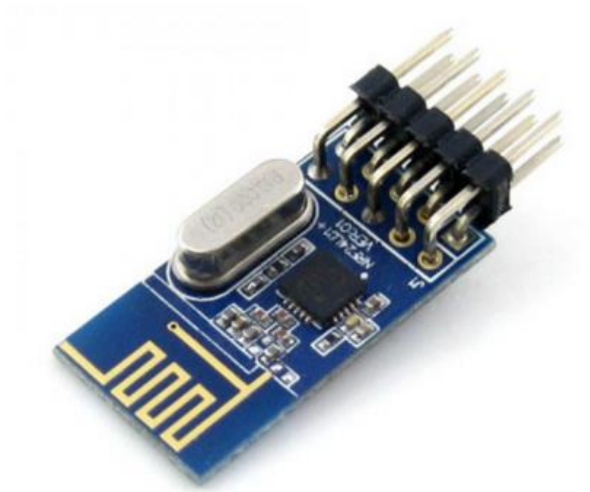

Fig. 3.1 nRF24L01 RF Board (B). Source: http://www.waveshare.com

3.2. USB Hi-Speed – MPSSE Cable (C232HM-DDHSL-0)

This cable is able to transmit the data sent by the computer through a USB port into the nRF24L01+ and vice versa, acting as a link between them. Although it is not of paramount importance for this project, the datasheet [2] covers every characteristic and functionality regarding this device.

Fig. 3.2 USB Hi-Speed – MPSSE Cable. Source: www.ftdichip.com.

3.3. Connections

NRF24L01 pins:

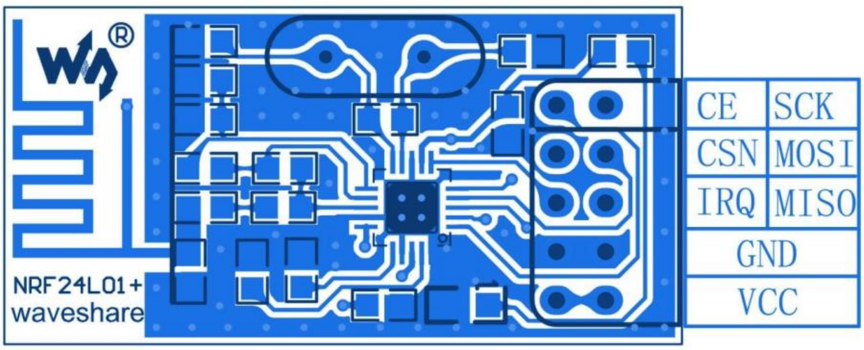

Fig. 3.3 NRF24L01 RF Board (B) Pin Definition. Source: www.waveshare.com.

MPSSE Cable Connections:

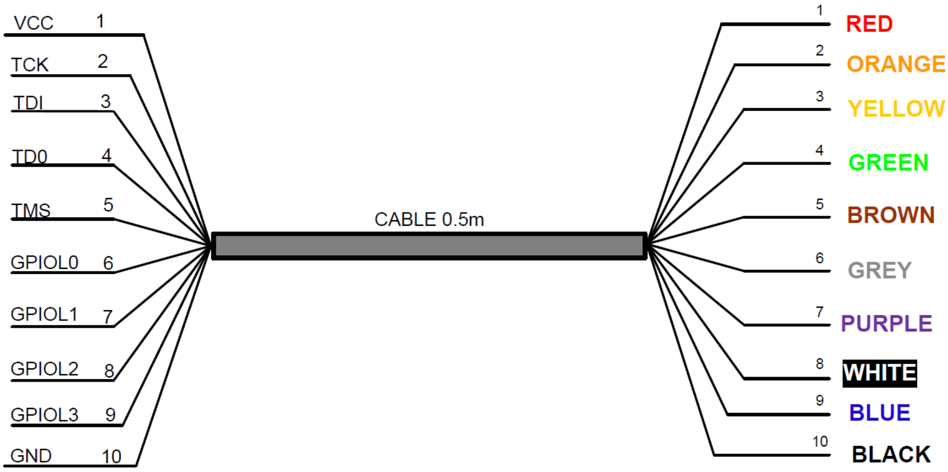

Fig 3.4 C232HM MPSSE Cable Connections (JTAG nomenclature). Source: www.ftdichip.com.

The cable description as shown in Fig. 3.4 can be found in this cable datasheet [2]. It is important to draw attention to the fact that although the figure uses JTAG nomenclature, the SPI interface will be used for this project, which is displayed in the datasheet [2] as well.

Table 3.1 represents the connections that will be used over the whole project:

NRF24L01	MPSSE Cable
CE	GPIOL1 - Purple
SCK	SK - Orange
CSN	CS - Brown
MOSI	DO - Yellow
MISO	DI - Green
GND	GND – Black
VCC	VCC – Red

Table 3.1 NRF24L01 – MPSSE Cable connections. Own source.

Figure 3.5 shows these connections:

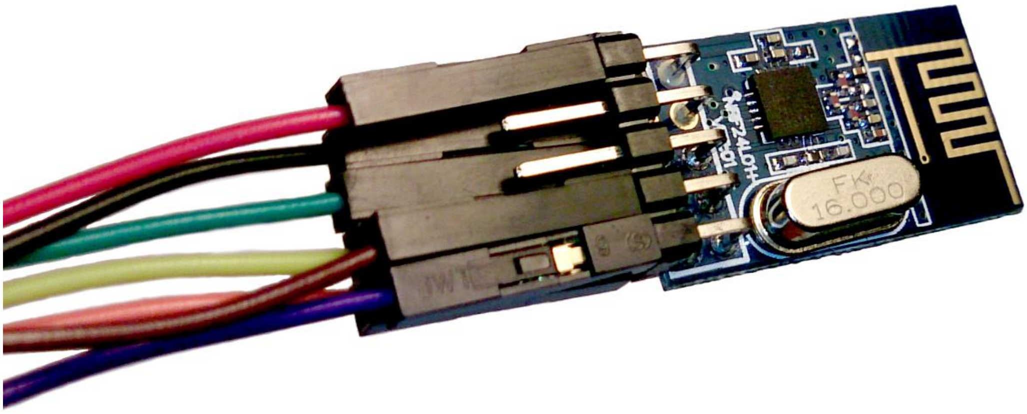

Fig. 3.5 NRF24L01 – MPSSE Cable connections. Own source

On the other side of the cable there is a USB Hi-Speed connection which is going to be connected to the PC.

Fig. 3.6 USB Hi-Speed - PC connection. Own source.

Fig. 3.7 shows the whole sniffer (NRF24L01 + USB Hi-Speed – MPSSE cable + PC):

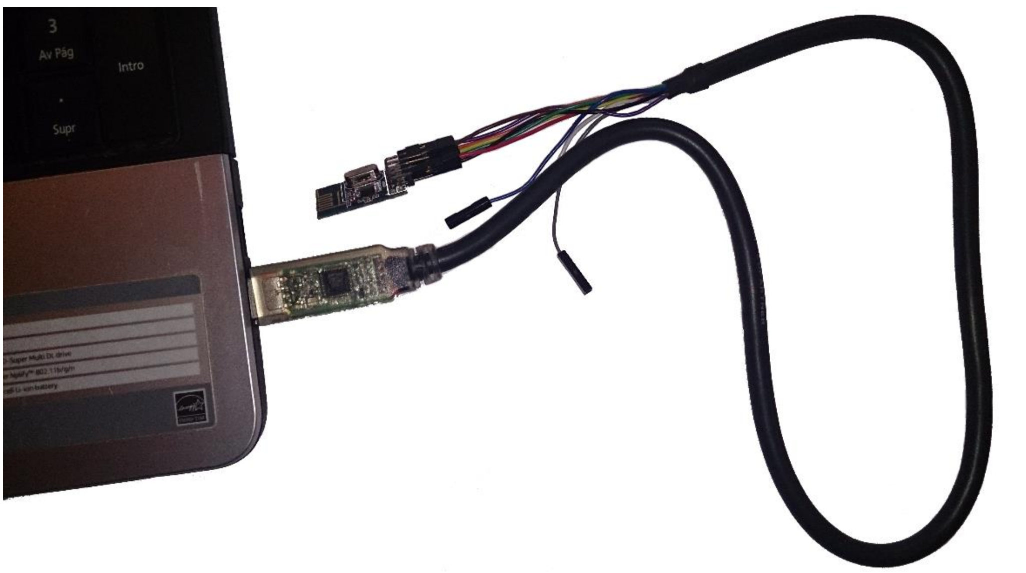

Fig. 3.7 Sniffer hardware. Own source

4. Software structure

This project has been designed with a structure based on software layers, as shown in Fig. 3.8. It covers from the libraries upon which the whole program is sustained to the GUI and all of its elements that allow eventually the interaction between the user and the NRF24L01.

The whole project consists of 7 python files. The following diagram provides a clear vision of the relationships between this files and its classes:

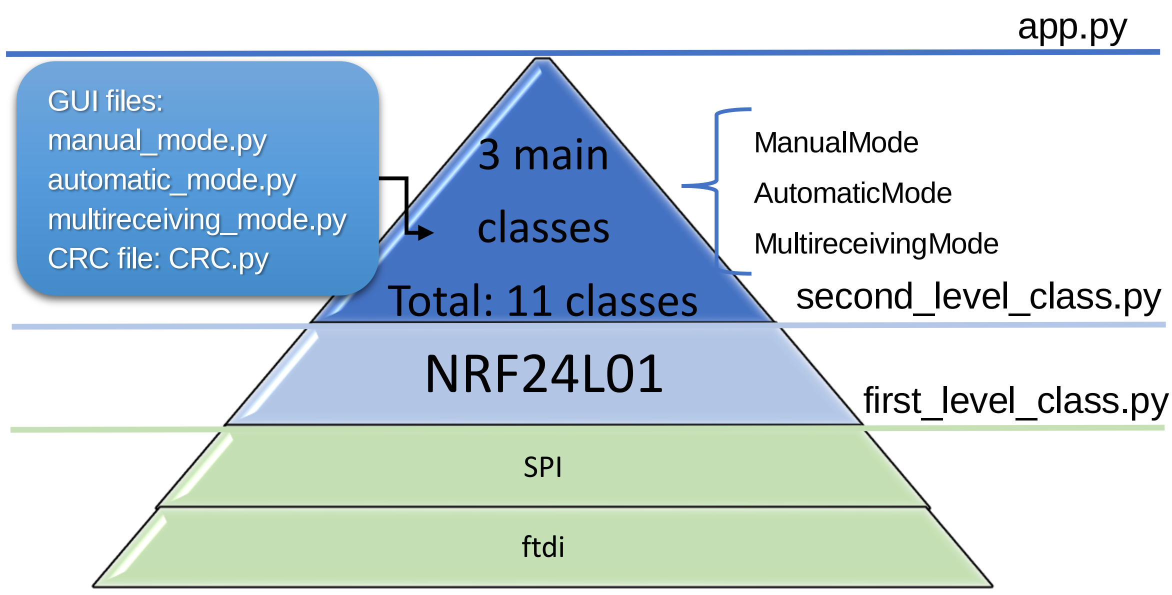

Fig. 3.8 Software structure. Own source.

Note there are a few files which support the app.py file such as the GUI and the CRC files, that do not inherit from the first or second level classes. This report will cover from the base to the top of the shown software pyramid.

5. Libraries

This section presents the libraries that have been taken from other authors [3, 4] and have been modified and optimized to fit the needs of this project.

5.1. First level classes: ftdi and SPI

These two classes [3], once have been adequately modified (annex A.1), are able to transmit and receive data through the FTDI cable. However, it is important to take into account that these classes were not built to support communication with a NRF24L01. In fact, they were only able to detect the cable and read registers. Moreover, module d2xx needs to be installed.

The most important elements of these classes are the *read* and *write* methods from SPI class. Almost every method in this file lives to eventually support these two functions. Therefore, it is necessary to understand how they work.

write() **method**

In order to write (actually overwrite) a register, first thing to do is to tell the NRF24L01 (SPI Slave) that it has to be prepared to receive data. This is achieved by activating the *Chip Select* pin, which means setting CSN low (note this is an active low signal). Then, the chip wants to know what it is supposed to do, that is why a one-byte command must be sent through the MOSI pin (DO from the ftdi cable). In this case, the command is “001AAAAA” in binary code, where “AAAAA” is the 5-bit Register from the map address [1]. This command is represented in Fig. 5.1 from bit C7 to C0. While this command is sent, status information is received from the chip (S7 to S0), which is most of the times ignored. Afterwards, the information that will be overwritten on the register must be sent (note that CSN keeps *low* during all this process as it will be of paramount importance later on). Finally, CSN is set *high,* which is understood by the chip as an end of the transaction.

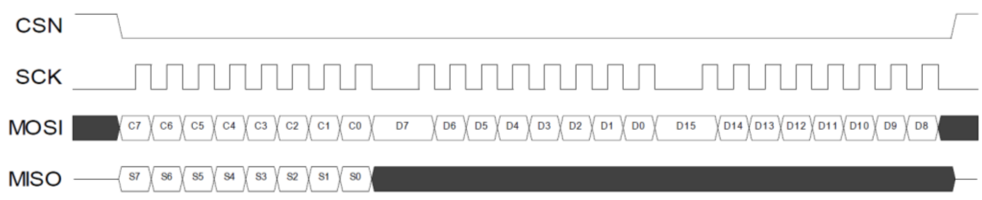

Fig. 5.1 SPI write operation. Source: SparkFun Electronics.

read() **method**

It is basically the same process although the command that needs to be sent is “000AAAAA” in order to read the register “AAAAA”. After that, register information is sent through the MISO connection from the NRF24L01.

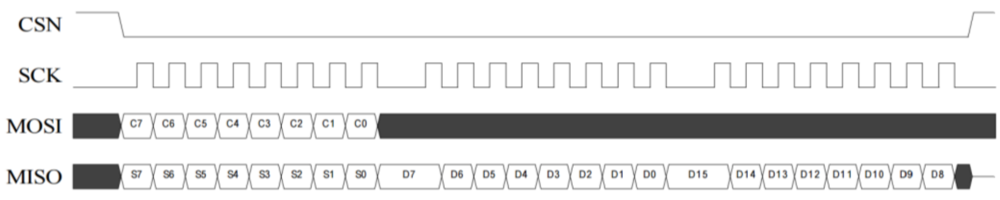

Fig. 5.2 SPI read operation. Source: SparkFun Electronics.

If these two methods work properly it can be assured that both ftdi and SPI classes work just fine. Unfortunately, this was not the case as mentioned before. The reason was found after a thorough learning of the classes and how the NRF24L01 board needs to receive the information. The original *write()* method allowed sending one byte to the chip and this method included setting the CSN *low* at the beginning and *high* at the end of the process. This detail is not easy to acknowledge as the method does not directly specify it. Therefore, it was impossible to write a register because at least two bytes need to be sent with CSN set low. The following chart shows a write and read process using the original classes:

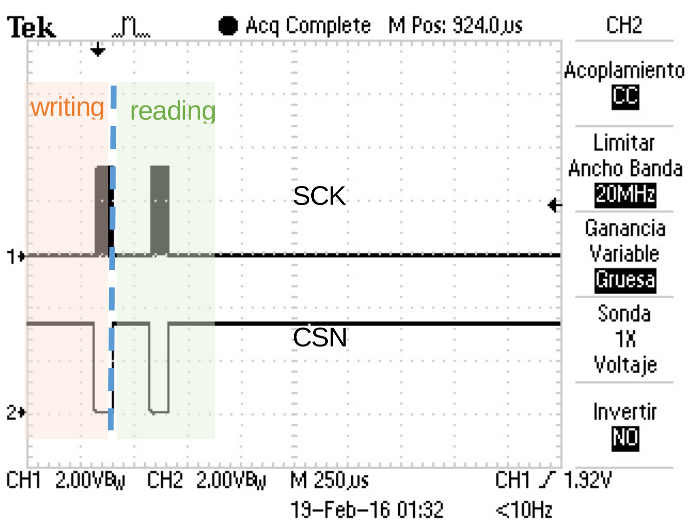

Fig. 5.3 Reading process using the original library. Source: Electronic Engineering Department ETSEIB – UPC.

Fig. 5.3 shows the SCK output of the FTDI cable, which is the SPI Clock signal, and the SPI Chip Select signal CSN. The reason for choosing the SCK to show the two processes is simply because this signal shows when communication is taking place so that both writing and reading processes can be seen. Every peak level represents a byte sent or received regarding the *write* and *read* methods explained before. It is easy to see that the CSN signal is not working properly. Here is how it performs once the original library has been modified:

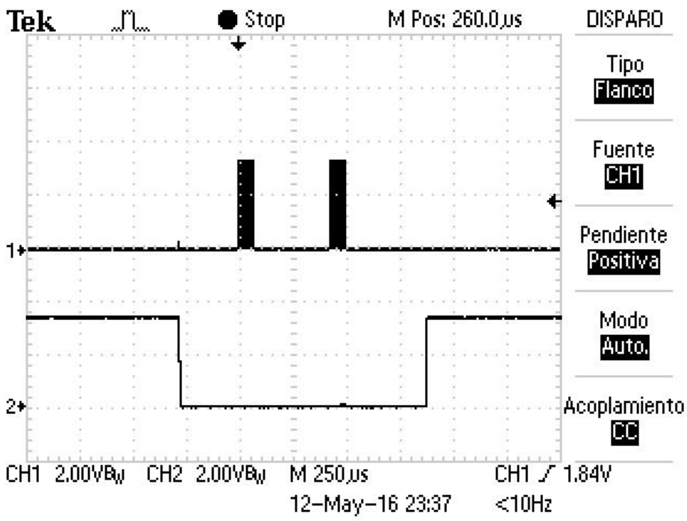

Fig. 5.4 Reading process with the modified library. Source: Electronic Engineering Department ETSEIB – UPC.

Once the problem was identified, the next step was to decide how to modify these methods in order to optimize their utility. Since the number of bytes written and read could vary depending on what was read or written (not only one byte registers), the decision of removing CSN actions was taken. Thus, the function of these methods has been limited to reading and writing one byte. This allows great flexibility when building upper level classes. Moreover, the classes have been modified in terms of removing useless methods and duplicities, in order to adapt the code to meet this project needs. A full description of the methods regarding these classes can be found here. Annex A.1 provides the python file containing both classes.

5.2. Second level class NRF24L01

Although first_level_class.py provides basic communication with the chip, a more complex communication process is needed as the main objective is to be able to receive and send data from and to another device. A *micropython* NRF24L01 class [4] has been used for this purpose. Since this project does not operate with *micropython* it is necessary to adapt the code in that sense. In addition, it is especially important to fully understand the methods of the NRF24L01 class in order to link successfully this class with the first level classes. A full description of the file that contains this class is available here. The full code is available in annex A.2. These are the main characteristics regarding this class.

Resetting and initializing

SPI class must be initialized so that all of its methods are available and ready to use. After initialization, every relevant register is set to a default value.

***Low(pin)* and *high(pin)* methods**

Set CSN or CE (Chip Enable) into a low or high level. These methods, coupled with the *read* and *write* from the SPI class, give free rein to the other methods to perform any communication process with total flexibility.

***Reg_read()* and *reg_write()* methods**

These functions were specially built to read and write registers because of its use all over the code. With these methods the NRF24L01 device can be freely configured. The class contains a bunch of methods which permit a direct and intuitive configuration of the most important registers such as *flush_rx(), flush_tx(), set_power_speed(), setcrc(),...*

Listening methods

This class also contains methods that will be used in a listening process such as:

- ***open_rx_pipe***: enables the pipe and the autoacknowledgement feature for that pipe (which will be explained later) after writing the address in the correct pipe. In case the pipe number is 2 or more, the last 4 bytes will be stored in pipe 1 address register and the first one (in case the address is 5 bytes long) is stored in the respective pipe. Note that all the pipes must have the same length.

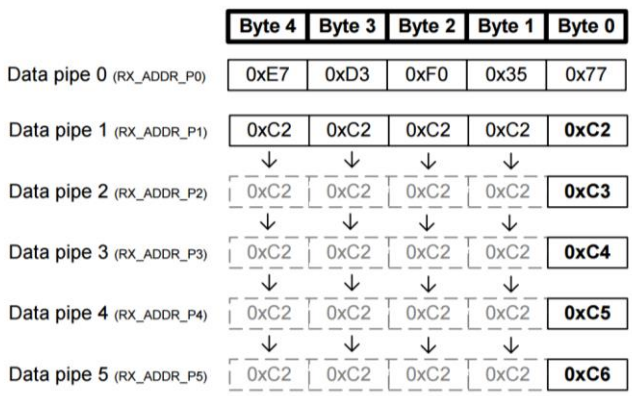

Fig. 5.5 addressing data pipes. Source: SparkFun Electronics.

- ***start_listening()*:** it sets the chip in a RX mode, which means that the device is listening from this point on. Besides, the FIFOs are cleaned to ensure that new data can be stored.

- ***stop_listening():*** *sets the chip back to a standby mode which prevents the NRF24L01 from capturing more packets.*

- ***start_sending(msg):*** *sends a packet containing the message "msg" according to the configuration that has been applied to the chip.*

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6. GUI

Before reaching the top of the pyramid, it makes sense to explain how the Graphic User Interface has been built as in the next section everything will be put together.

PyQt4 [4,5], a python module from Riverbank computing (www.riverbankcomputing.com), has been used for this purpose. According to Riverbank computing [5], *PyQt is a set of Python v2 and v3 bindings for The Qt Company's Qt application framework and runs on all platforms supported by Qt including Windows, MacOS/X and Linux. The bindings are implemented as a set of Python modules and contain over 1,000 classes*. Although it provides a handful of components, only QtGui and QtCore will be used for this project.

Besides, the GUI has been developed using Qt Designer, which is a Qt's tool that helps building a GUI. It basically consists on dragging and dropping elements onto a window until you got everything you need. Then, it just needs to be saved and converted to a py file format. It is worth mentioning that although this is a useful tool, the result is a really basic GUI, which makes almost inevitable the manual modifications of the given class.

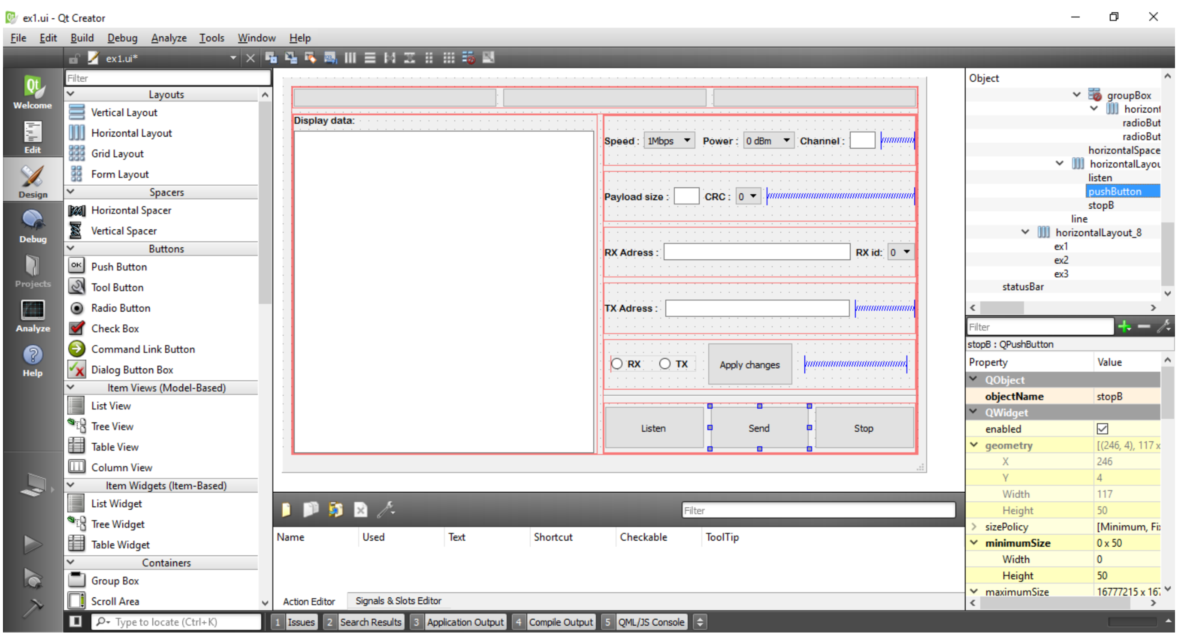


Fig. 6.1 Qt Designer interface. Shaping the GUI. Own Source.

The developed application is formed by three GUI classes according to each mode available in the app. Every class is contained in a different file, so that the reader can quickly distinguish between interfaces. These files are *manual_mode.py*, *automatic_mode.py* and *multireceiving_mode.py*. It is important to draw attention to the fact that the classes that are going to be explained here are the final result from a series of intermediate steps which goes from the most basic GUI developed with Qt Designer to a more complex layout (manually modified). Here is a before/after layout:

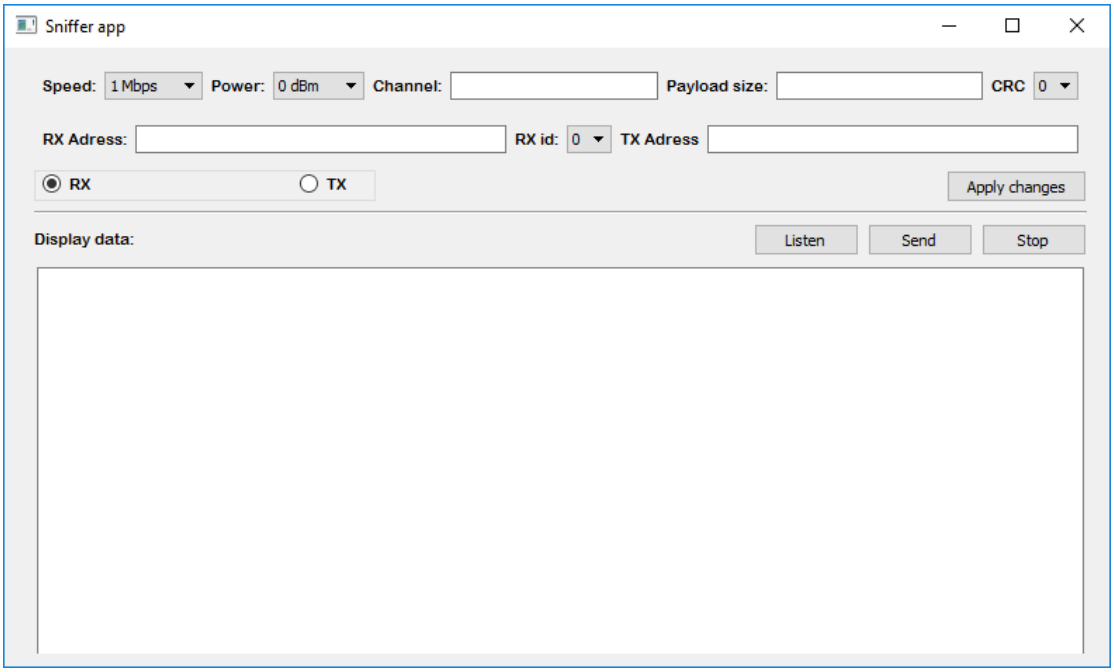


Fig 6.2 First basic layout made with Qt Designer. Own source.

Fig 6.3 Final layout (manually modified). Own source.

It is easy to notice that lots of components have been "faked" to meet professional layout expectations. This means more complexity and accuracy.

In an attempt of trying to avoid a detailed explanation of every component of the layout (which the reader can find in the bibliography [6] and the component's code in annex A.4, A.5 and A.6), this section will present the most significant characteristics of the final GUI.

6.1. Title bar

As the reader might have noticed, no title bar is displayed on the final layout. The reason for this is just esthetical. An effort to build the GUI as a unique unit has been made. Therefore, a completely customized title bar has been created. Although this could seem straightforward, there is more work behind it than the reader might expect. PyQt4 does not provide the kind of title that meets this project expectation. Therefore, a bit of imagination was needed in order to build the functions that are usually found in a title bar. These are: window movement, minimize, maximize and close window. Maximize is useless in this case, as the app uses just the necessary space for the app.

6.2. Minimize and close buttons

The two functions that provide functionality to these buttons are *app.quit()* and *myapp.minimized()*. There is something important to draw attention on which applies to every button. They are there, but the user is not able to see them. Knowing this may be difficult to understand and that a picture is worth a thousand words:

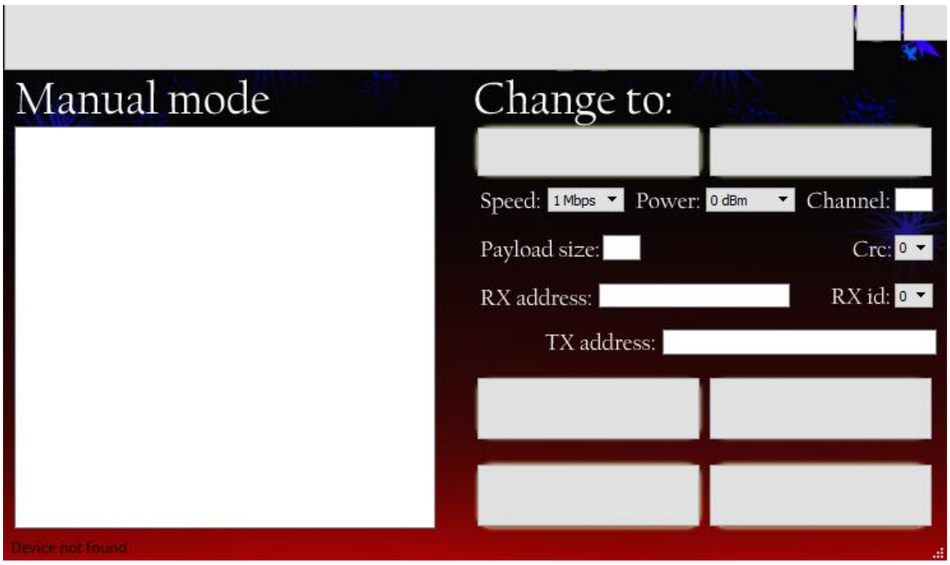


Fig. 6.4 Real buttons in the app's layout. Own source.

These buttons are set transparent so that the more stylish button’s images can be visible.

6.3. Labels, input fields and output fields

This application contains no labels (or at least, no visible ones). This decision was taken to provide the professional appearance this project is looking for coupled with the fact that it is easier to deal with an image than with the rigid layout that PyQt4 offers.

Input fields have been kept untouched. There are input lines, picklists and a text browser which displays all the information. Each of them serves a specific purpose.

6.4. Status bar

It indicates the user whether the Device is connected or not. Therefore, there will always be a QThread class method running periodically to update the connection state.

7. app.py file

Once all the necessary tools to build this application have been exposed, it is time to put everything together and make it work. Since the app will display three configuration modes, it has been considered sensible to maintain the same structure in the code as well. Therefore, in the app.py file, three main classes (ManualMode, AutomaticMode and MultireceivingMode) can be found corresponding to each mode. The other classes support these latter ones. This file acts as a controller which manages the input parameters and actions that the user displays through the GUI and translate these inputs into actions that the NRF24L01 class can understand and vice versa. Detailed documentation about this file can be found here. The full code is available in annex A.3. This is how this section will be structure:

- GeneralModeFunctions class
- QThread classes
- Manual mode
- Multireceiving mode
- Automatic mode
- Tests

7.1. GeneralModeFunctions class

Since most of the methods and attributes are similar in every mode class (if not equal), the decision of joining all these methods and attributes together in one single class was taken. This class was named `GeneralModeFunctions`.

7.1.1. Inheritance

Because these mode classes inherit from *QtGui.QMainWindow*, `GeneralModeFunctions` needs to inherit this class to actually be able to execute the methods and attributes from the mode classes without problems. This is the inheritance structure:

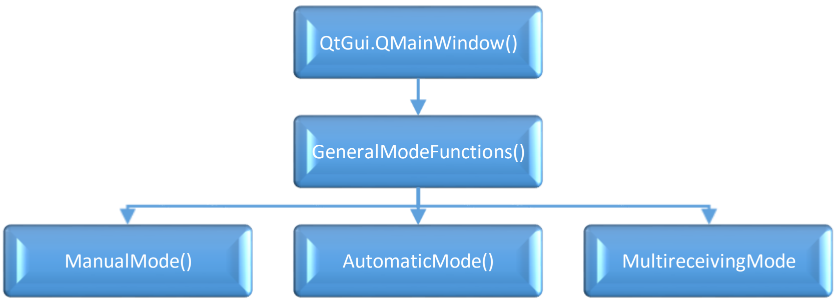


Fig 7.1 Mode classes' Inheritance structure. Own source.

7.1.2. Methods

These methods are available to every mode class.

7.1.2.1. listening()

It is triggered when clicking the "Listen" button. This function is a very important one not only because it sets the NRF24L01 in a listening state but also because in order to do that, it has to call another class named ListeningLoop which is a thread. The reason of being of this thread is the need of a loop when listening. If the loop was written in this method, the app would get stuck and would not respond. Therefore, the loop must be executed in another class that runs simultaneously together with one of the mode classes. If the method fails execution, a message will let the user know whether it is due to a loss of connection or because the parameters have not been applied yet. If it is owing to a loss of connection by popping up a message box informing the user about the problem.

7.1.2.2. stop_listening()

It runs when the "Stop" button is clicked. It makes the NRF24L01 stop listening, which means returning to a standby state (which also consumes less energy). A message confirming the execution of this method is shown on the text browser. If the method fails, it will proceed as in the *listening()* method.

7.1.2.3. end_Get_CheckConnection()

It is executed when a signal is received from `GetConnection` or `CheckConnection` class. That is, when connection is established or lost. It just updates the status bar, terminates the thread from which the signal comes from and starts the other one. Note that there is always one thread running, `GetConnection` or `CheckConnection`.

7.1.2.4. add_to_record(s)

Normally, displays information to the user via the text browser. It also saves the displayed information in a text file named as the mode that is currently running. This information is overwritten every time the app is executed. This avoids deluging the folder with hundreds of files. Nevertheless, if Focus or Fast file download modes are enabled it plays a whole different role which is explained in detail on the sphinx documentation available here.

7.1.2.5. Change_mode()

This method is executed when the user presses the “Manual mode”, “Automatic mode” or “Multireceiving mode” button. It closes the current GUI and opens a new one according to the mode that the user chose. It also terminates the threads if they were running and passes the new window's position.

7.2. QThread classes

All the classes that are presented in this section inherit from QtCore.QThread and are isolated from the main classes for one of two reasons. A huge number of calculations take place in their *run()* method which prevents the app from running correctly, which is the case of packet_validation(), or because these classes’ *run()* method contain a loop that needs to be executed simultaneously together with the current mode class. Note that all these classes automatically execute its run method (where all the code is located) when the class is started. These classes are:

7.2.1. Intro class

This class is only initialized and started by `ManualMode` class. It is only executed the first time that `ManualMode` is called. It provides a 3 seconds Introduction image to the app and its owner which is the following.

Fig. 7.2 Introduction image to the app. Own source.

7.2.2. Move class

Since this app has an especial title bar and the function of dragging the window is executed when pressing long invisible button at the top of the window, this functionality is carried out by this class. Whenever the button is "pressed" (not clicked), the *run()* method from this class is executed. This method consists of a loop which maintains the relative distance (and angle, of course) between the mouse and the window while the button is pressed. Nevertheless, it is possible that the loop does not update fast enough the relative distance which causes the mouse being outside the button which stopped the loop because the mouse was no longer pressing the button but another part of the screen. This problem was tackled by focusing on the on the mouse state (left click pressed or not pressed) instead of focusing on the button once the button was pressed.

7.2.3. GetConnection class

This class is triggered every time the device is disconnected. Therefore, it will run at least one time, right at the beginning. It basically consists of a loop that is constantly trying to stablish communication with the device. If it can, the state of the status bar will change to "Connected" in green and a message confirming this connection is displayed in the text browser.

Fig. 7.3 Status bar states. Own source.

7.2.3.1. Checkconnection class

Whenever the `GetConnection` loop stops running, the `Checkconnection` loop does. In this case, this loop does not check the device connection, as this would mean sending information through the FTDI cable and expecting something in return. This is not good practice since the app could be applying parameters or be in the listening loop while this happens which would turn out badly due to the fact that both signals would be sent through the cable simultaneously. Notwithstanding this, it is possible to check the cable's connection without interfering with the device and this is what this class actually does.

7.2.4. ListeningLoop class

It runs a loop in which it checks if the *any()* method from the NRF24L01 class returns True and, if so, sends a signal to the current mode class when something is received. If the device is disconnected while running this loop, a signal is sent to the current mode class which triggers a method that pops up a message on the screen informing of this unexpected disconnection.

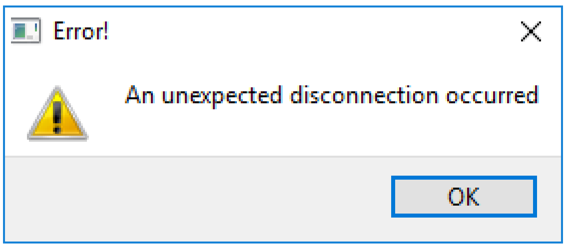


Fig. 7.4 Error message box due to an unexpected device disconnection. Own source.

7.2.5. PacketValidation class

This class is of paramount importance not only for its complexity but also because it to catch a packet without knowing almost anything about it. The process regarding this class will be tackled in section 7.5.4.

7.3. Manual mode

The purpose of this mode is to establish communication either with a transmitter and a receiver. As the title of this mode reveals, all the relevant parameters regarding this communication will be modifiable by the user. These are the relevant settings that must be taken into account when receiving and sending packets:

- **Air data rate** [1 Mbps, 2 Mbps, 250 Kbps] – input value

  According to the NRF24L01 datasheet [1], *"Using lower air data rate gives better receiver sensitivity than higher air data rate. But, high air data rate gives lower average current consumption and reduced probability of on-air collisions. [...] A transmitter and receiver must be programmed with the same air data rate to communicate with each other"*.

- **Channel** [0 to 125] – input value

  According to the NRF24L01 datasheet [1], *"You must program a transmitter and a receiver with the same RF channel frequency to communicate with each other"*.

- **Static payload length** [1 to 32 Bytes] - input value (only for receiver mode)

  Must be the same length as the sent message, otherwise the chip will not get the correct CRC (as it sent right after the message) causing a CRC failure and discarding the packet.

- Enable **CRC** (although is forced to be enabled when Auto Acknowledgement is enabled.)

  [1]: *"The CRC is the mandatory error detection mechanism in the packet. It is either 1 or 2 bytes and is calculated over the address, Packet Control Field and Payload"*.

- **CRC** [1 or 2 bytes] - input value

  Must be the same as the transmitter, otherwise will cause a CRC failure and the packet will be automatically rejected unless it is deactivated from the receiver side.

- **Pipe** enabled [pipe 0 to 5] – input value (only for receiver mode)

  Only one pipe needs to be enabled in this mode.

- **Enhanced ShockBurst** enabled for the chosen pipe

  Normally, messages are sent with Enhanced ShockBurst enabled.

- Pipe address – input value

  Must be the same as the transmitter address and set in the pipe address that has been enabled

- `PWR_UP, PRIM_RX` registers and CE must be set high to enter in RX mode
  `PWR_UP` - if set high, the NRF24L01 enters standby-I mode.
  `CE` - if set high, the NRF24L01 enters standby-II mode.
  `RIM_RX` - if set high, the device enters in RX mode.

- **Dynamic Payload –** This feature permits automatic payload detection for the receiver only if Dynamic Payload has been enabled from the transmitter, otherwise the payload length will not be set in the transmitted packet

The following table shows how both the receiver and the transmitter should be configured to be able to communicate with each other:

Input Settings

Air rate	Same for the receiver and the transmitter
Channel	Same for the receiver and the transmitter
CRC	Same for the receiver and the transmitter
Pipe	Not relevant
Pipe address	Same for the receiver and the transmitter

Registers’ configuration

Register	Receiver	Transmitter
00	0b1001 (1 byte CRC) 0b1101 (2 bytes CRC)	0b1000 (1 byte CRC) 0b1100 (2 bytes CRC)
01	0b111111 – Enhanced ShockBurst enabled in all pipes	Not relevant

02	0b111111 – Enable all pipes	Not relevant
03	Address width for all pipes	Address width (related to register 10)
04	Not relevant	Not relevant
05	Same for the receiver and the transmitter	Same for the receiver and the transmitter
06	Same for the receiver and the transmitter	Same for the receiver and the transmitter
07	Not relevant	Not relevant
08	Not relevant	Not relevant
09	Default	Default
0A	One of these registers must fit the TX address sent by the transmitter (notice LSB is written first)	Not relevant
0B	The register that corresponds to the chosen pipe to receive the information must have the same length as the TX address from the transmitter	Not relevant
0C		Not relevant
0D		Not relevant
0E		Not relevant
0F		Not relevant
10	Not relevant	The introduced address must equal the chosen RX pipe address (notice LSB is written first)
11	Choose the desired payload width for the chosen pipe	Not relevant
12		Not relevant
13		Not relevant

14		Not relevant
15		Not relevant
16		Not relevant
17	Default	Not relevant
1C	Not relevant	Not relevant
1D	Not relevant	Not relevant

Table 7.1 Registers' configuration. Own source.

If all these registers were overwritten in both the transmitter and the receiver and CE signal was set high in both chips (first on the receiver and then the transmitter so that the message can be received before being sent and not after), the message should be saved in the RX FIFO from the receiver which can be easily accessed with the R_RX_PAYLOAD command as will be shown in the following section.

7.3.1. ManualMode class

The mode classes contain the specific attributes and methods regarding the mode (annex A.3).

7.3.1.1. The constructor

As this class inherits from `GeneralModeFunctions`, two parameters must be passed to the inherited class which are: an instance of the GUI class from the corresponding mode and the name of the text file that is going to be used as a record.

This class needs no other attribute to run properly (apart from the ones inherited). However, there is a short presentation which turns up every time the program is executed where the logo of the app appears together with the owner's name.

It is actually very basic. There is a global variable which is *True* by default so that the first time the *if* statement is executed, it initializes an *Intro()* instance and then starts the *QThread* class. This *QThread* class (*Intro()*) runs automatically its method *run(),* which makes the program wait for 3 seconds before hiding the intro and letting the user see the Manual mode interface.

7.3.1.2. *apply_new_parameters()* method

It tries to apply the input parameters chosen by the user into the NRF24L01. If it fails a message box will tell the user whether is it due to an unacceptable input or because the app lost connection with the chip (if this is the case, GetConnection class will be started, which will wait for the device to be connected). If it succeeds, parameters will appear on the text browser together with a message confirming the success. It also checks if the user has clicked on *stop_listening()* after clicking on listening. If not, *stop_listening()* method is executed before applying the parameters.

7.3.1.3. *read()* method

It gets the message by calling the *recv()* method from the NRF24L01 class and prints it on the text browser

7.3.1.4. *tx_message()* method

Opens an input window were the user can write the message that wants to send. The message must be written as in the Address input field. When the user clicks the "OK" button this method calls the *sending()* method.

7.3.1.5. *sending()* method

This method actually sends the packet by calling *start_sending()* from the NRF24L01 class. After that, it checks whether the message was correctly sent. Then it waits for the acknowledgement packet in case that option was checked by the user. When the acknowledgement packet has been received, a message informs the user about that fact.

7.3.2. Example

In this example, both the transmitter and the receiver can be configured with this application as will be shown.

The transmitter and the receiver will have the following characteristics:

- **Address:** 0xB2B3B4
- **Message (transmitter):** 0x01
- **Air rate:** 1Mbps
- **Power (transmitter):** 0 dBm
- **CRC:** 1 byte
- **Pipe number used (receiver): 0**

Using the app, the chip configuration is as follows:

Register Map configuration

Register	Receiver	Transmitter
00	0x09	0x08
01	0x01	0x3F
02	0x01	0x3F
03	0x01	0x02
04	0x68	0x0A
05	0x40	0x40
06	0x7	0x07
07	0x0E	0x0E
08	0x00	0x1A
09	0x00	0x00
0A	0xB4 0xB3 0xB2	0x01 0x04 0xB3
0B	0x00	0xC2
0C	0x00	0xC3
0D	0x00	0xC4
0E	0x00	0xC5
0F	0x00	0xC6
10	0x00	0xB4 0xB3 0xB2
11	0x01	0x05
12	0x00	0x00
13	0x00	0x00
14	0x00	0x00

15	0x00	0x00
16	0x00	0x00
17	0x11	0x01
1C	0x3F	0x3F
1D	0x3F	0x3F

Table 7.2 Registers' configuration example. Own source.

Now, let's see how easy it is to configure both the receiver and the transmitter with this app.

It is not important to have the device connected when starting the app, although it will be necessary when applying the parameters. A message will turn up on the text browser if the connection has been successful. Moreover, we can quickly check the state of our connection in the status bar, which, if the device has been connected properly, will display "Connected" in green.

Fig. 7.5 Manual mode interface. Own source.

Then we can proceed to introduce the input parameters as the app opens Manual mode by default. There are a couple of things that must be taken into account when introducing the parameters.

- All numbers must be written as in hexadecimal format separating every byte with a space. For example: b1 b3 c5 01
- The address can be of 3, 4 or 5 bytes long
- The address is written in reverse to the register it is written from the Least Significant Byte (LSB) to the Most Significant Byte (MSB). That is because it is easier to understand the address writing first the MSB (this will be of paramount importance in the Automatic mode).

Receiver:

The transmitters code for this example is available in annex C. This configuration can be easily set throughout the app by fulfilling the parameters and clicking on “Apply parameters”.

Fig. 7.6 Screenshot after clicking on “Apply parameters”. Own source.

Now we just need to click on “Listen” to start receiving packets:

Fig. 7.7 Screenshot after clicking on “Listen”. Own source.

When the packet is sent from the transmitter, the receiver catches that packet and shows its message on the text browser:

Fig. 7.8 Screenshot after receiving the packet. Own source.

Transmitter:

Similarly, we can configure the transmitter:

Fig. 7.9 Screenshot after clicking on “Apply parameters”. Own source.

As we want to send a message, we just need to click on “Send” and the following window will pop up:

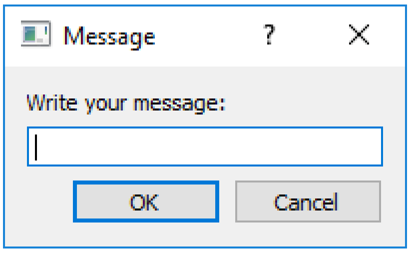


Fig. 7.10 Screenshot after clicking on “Send”. Own source.

The message must be written in the same way as the address. After clicking “OK”, the message will be sent and a message confirming this fact is displayed on the text browser.

Fig. 7.11 Screenshot after clicking on “OK”. Own source.

7.4. Multireceiving mode

Once all the problems from the Manual mode have been overcome, this mode turns out really simple (annex A.3). The strong point of it is the capacity of receiving messages from different addresses, this is, the possibility to communicate among different devices at the same time. This can be achieved thanks to the 6 receiving pipes integrated in the NRF24L01.

7.4.1. Multireceiving_mode class

The methods that make this class work are the followings.

7.4.1.1. apply_new_parameters()

This method configures the NRF24L01 to be ready for listening. Notice that this method leaves the chip in a low energy consumption state. This means, it is not “listening” yet. Here is the configuration table where the reader can see which fields are required and how they must be fulfilled.

Input Settings

Air rate	Same for the receiver and the transmitter
Channel	Same for the receiver and the transmitter
CRC	Same for the receiver and the transmitter
Pipe	Not relevant
Pipe address	Same first three bytes for the receiver and the transmitter

Register Map configuration

Register	**Receiver**	**Transmitter**
00	0b1000 (1 byte CRC) 0b1100 (2 bytes CRC)	0x0C
01	0b111111 – Enhanced ShockBurst enabled in all pipes	Not relevant
02	0b111111 – Enable all pipes	Not relevant
03	Address width for all pipes	Address width (related to register 10)
04	Not relevant	Not relevant
05	Same for the receiver and the transmitter	Same for the receiver and the transmitter
06	Same for the receiver and the transmitter	Same for the receiver and the transmitter
07	Not relevant	Not relevant
08	Not relevant	Not relevant
09	Default	Default
0A	One of these registers must fit	Not relevant

0B	the TX address sent by the transmitter (notice LSB is written first)	Not relevant
0C		Not relevant
0D		Not relevant
0E		Not relevant
0F		Not relevant
10	Not relevant	The introduced address must equal one enabled RX pipe address (notice LSB is written first)
11	The pipe that is going to be used must have a 32 bytes payload width	Not relevant
12	Not relevant	Not relevant
13	Not relevant	Not relevant
14	Not relevant	Not relevant
15	Not relevant	Not relevant
16	Not relevant	Not relevant
17	Default	Default
1C	Not relevant	Not relevant
1D	Not relevant	Dynamic Payload Length Enabled

Table 7.3 Registers' configuration. Own source.

7.4.1.2. read()

This method is similar to the *read()* from Manual mode. Nevertheless, it also prints the pipe from where the message has been caught on the screen so that the user can easily tell which transmitter is sending the information by checking the address of the pipe.

7.4.2. Example

Transmitter's code for this example is available in annex D. To perform this example and actually use the functionality that this mode provides, several transmitters are needed. For this example, 3 transmitters were used:

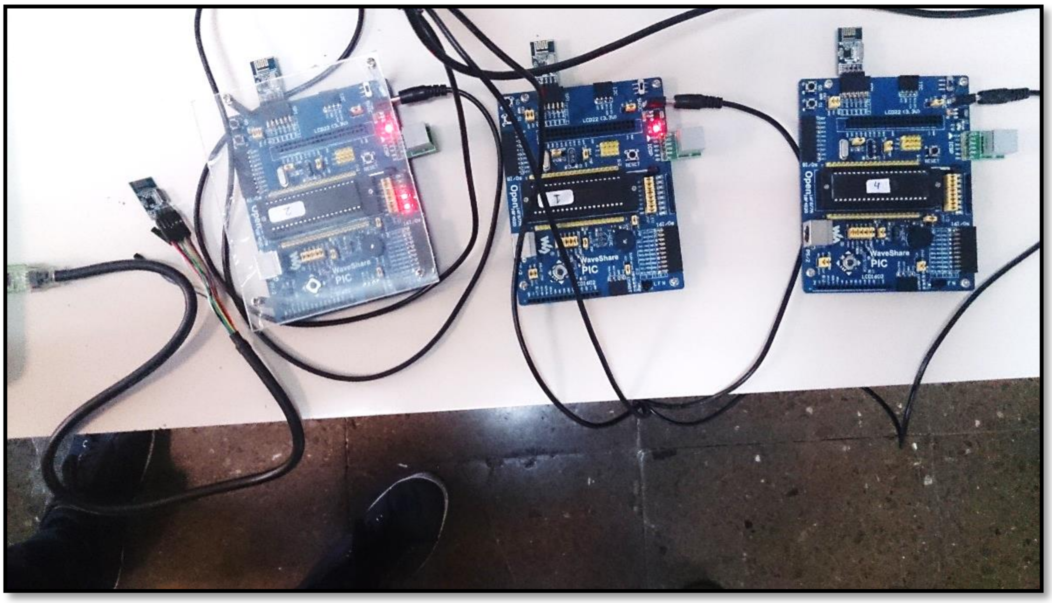


Fig. 7.12 Receiver (left hand) connected to the laptop and 3 transmitters connected to Open18F4520 boards. Own source.

These transmitters have been configured as follows (annex D):

Transmitters' packet characteristics

Addresses	0xB1 0xB2 0xB3 0xB4 0x01/02/03
Channel	64 (2464 [MHz])
Air rate	1Mbps
Power	0 dBm

CRC	2 Bytes
Dynamic Payload	Enabled
Message	1 2 4 8 15

Table 7.4 Transmitters' packet characteristics. Own source.

In order to receive all the packets sent by the transmitter, the following parameters must be set within the app to configure the receiver accordingly.

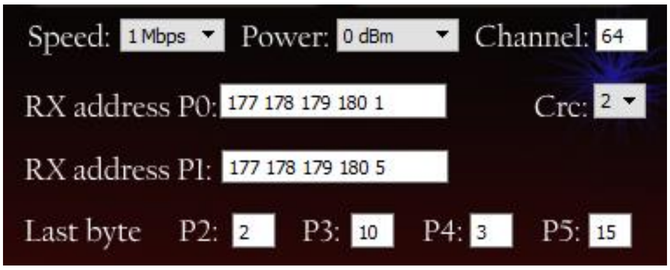


Fig. 7.13 Example parameters. Transmitters' addresses are set in pipes 0, 2 and 4. Own source.

After applying the parameters, the user just needs to click on "Listen" to be ready to receive packets. The following image shows the messages that have been received coupled with the pipe that contains the address from which the messages have been sent. This means that the user can easily recognise the transmitter that sent the message.

Fig. 7.14 Screenshot of the messages that have been received from different pipes. Own source.

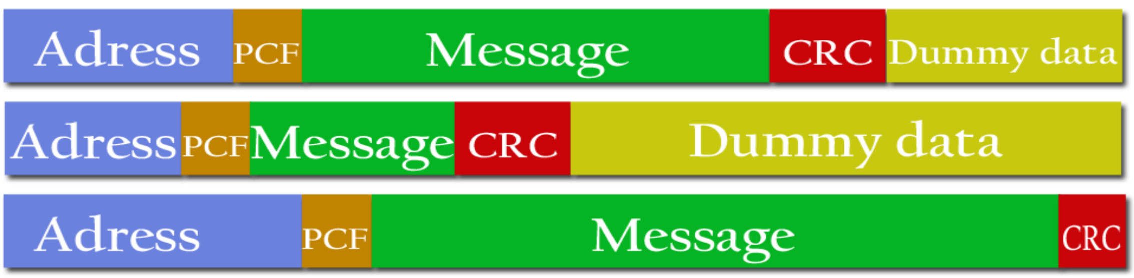
7.5. Automatic mode

This is probably the most complex mode in this application. Its aim is to get the message from a 3, 4 or 5 bytes address packet, knowing only the first 4 or even 3 bytes and nothing else (it also works with 5). This “nothing else” has important consequences. It allows the receiver to extract the message sent by different transmitters regardless of their configurations (address length, payload length and the CRC length). It basically reads every message contained in a packet that starts with the first 3 chosen bytes. The implications are impressive, however, this adds a lot of complexity to the message extraction, problems that will need to be tackled.

This mode is an enhanced variant of the so called Promiscuous Reading [10], which is the ability to receive a packet by knowing just a part of its address. It allows the receiver to get messages from up to 65793 different transmitters in contrast with the 6 different pipes that the device provides thanks to the Multireceiver functionality. Unfortunately, this Promiscuous Reading is not available in the NRF24L01, therefore, it will be applied manually using software.

This is achieved by configuring the receiver to receive a 3 or 4 bytes address with Enhanced Shockburst disabled. By doing so, the device will not check anything that comes after the address (mainly the CRC) and will just pass as much data to RX FIFO (first in, first out) as it can store (32 bytes).

Up to this point, the device is able to capture the packet, which contains the message. Nevertheless, this packet is hidden among many other bits. This means that the chip will not know either where the message exactly begins or where it ends. This makes it almost impossible to extract the correct message, even knowing it is among this large row of ones and zeros that the device has captured. Here are a few samples to exemplify this point:



[1]

Fig. 7.15 This figure shows that it is not possible (a priori) to know for sure where the message begins and where it ends. Own source.

The answer to this problem lies in the Enhanced ShockBurst packet structure. Messages are

[1] PCF (Packet Control Field) include the payload length, the PID and the no acknowledgement bit.

usually wrapped up in an Enhanced ShockBurst packet format. This packet contains (apart from the message) metadata such as the length of the message, the PID (Packet Identity), the No Acknowledgement bit and a CRC validation. These parts of the packet will not only help in the message extraction, but also provide important information about the transmitters configuration such as the CRC length and the full address which will be very useful in future sections.

7.5.1. Enhanced ShockBurst packet

As mentioned before, there are a bunch of elements wrapping up the message. Their distribution and length within the packet are:

Preamble (1 byte)	Address (3-5 bytes)	Payload length (6 bits)	PID (2 bits)	NO_ACK (1 bit)	Payload (0-32 bytes)	CRC (1-2 bytes)

Fig. 7.16 Enhanced ShockBurst packet distribution.
Source: http://yveaux.blogspot.com.es/2014/07/nrf24l01-sniffer-part-1.html

A detailed explanation of these elements, which is strongly recommended, can be found in the bibliography [1].

7.5.2. Receiving process

The receiver has the Enhanced ShockBurst mode disabled, this means that it is expecting a packet format like this:

Preamble 1 byte	Address 3-5 byte	Payload 1 - 32 byte	CRC 1-2 byte

Fig. 7.17 Packet distribution with Enhanced Shockburst disabled. Source: SparkFun Electronics.

We want no CRC to be verified from the receiver side, as we still don't know where this CRC is located. Instead the NRF24L01 will store the maximum data that the FIFO can keep to ensure that the entire packet is in between these 32 bytes

From now on, fixed lengths for the different fields will be provided to simplify the explanation as it can be easily extrapolated to different lengths. Let's say we have a 5 bytes message and we want the device to read the message with just the first 4 bytes of that address. The aim is that once the first 4 bytes of the address are checked, everything else passes to the RX FIFO in order to have free access to it.

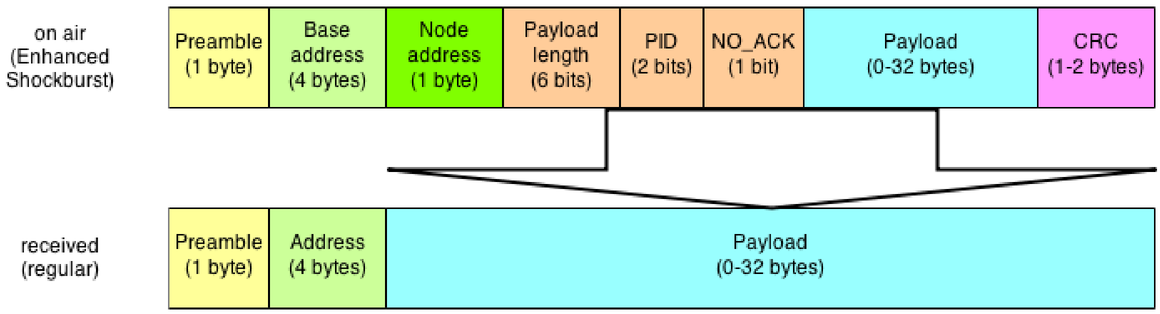


Fig. 7.18 The upper side packet represents a standard packet sent to the receiver. The other packet represents how the receiver sees the upper packet.
Source: http://yveaux.blogspot.com.es/2014/07/nrf24l01-sniffer-part-1.html

As can be seen in figure 7.13, the receiver (with Enhanced Shockburst disabled) checks the first 4 bytes of the received packet and stores the rest into the RX FIFO as if it was the message. The CRC must be disabled as the device does not know where the CRC is located. That is not a free of charge as when using a 3 bytes' address from the receiver side, some noise is captured by the device since just 3 bytes from the address must fit to capture the packet. This problem will be tackled later on.

Fig. 7.19 Noise detected knowing the first 3 bytes from the address. Own source.

Now, almost all the packet (except the first 4 bytes from the address that has been checked) can be accessed with the command R_RX_PAYLOAD.

In order to split the different sections of the packet, the information will be processed at a bit level rather than at a byte level due to the 9 bits of the Packet Control Field. The *Bitstring* module will be used for this purpose.

With all the packet information available in the RX FIFO a way needs to be found to locate every section of the packet in order to locate the message and the full address from where the message has been sent.

First thing to do is to delimitate the packet. Note that if the CRC is found, the packet will be delimited since it is located right at the end of the packet. However, that is only one advantage of finding the CRC. As we are going to see in the next section, finding the CRC will necessarily validate the message.

7.5.3. CRC

This section explains the importance of calculating the CRC [7, 8, 9] and the process that has been followed in order to manually get it. The CRC manual calculation is important for the following reasons:

- **Packet validation:** The CRC is calculated over the whole packet (excluding, of course, the CRC itself) to ensure that the receiver receives the right information from the transmitter. This is very helpful when receiving with a 3 bytes' address as it is easy to receive dummy data.

- **Guessing packets' payload length:** if payload length is unknown, it can be derived (as will be explained) once the CRC is located. This means knowing exactly where the message is located (because the end of the payload is the beginning of the CRC) and being able to extract it, which is the main aim of all these calculations.

Since the payload length is normally contained in the Packet Control Field (unless it is disabled), this mode will "guess" the packets' address length.

The consequence of using the CRC are impressive. Just by knowing the first 3 bytes of a message's address, this mode is able to present the message without errors.

But before delving into how to extract the message from a completely unknown packet, the CRC needs to be correctly calculated.

7.5.3.1. CRC manual calculation

According to the datasheet [1]:

"The CRC is the mandatory error detection mechanism in the packet. It is either 1 or 2 bytes and is calculated over the address, Packet Control Field and Payload.

The polynomial for 1 byte CRC is $X^8 + X^2 + X + 1$*. Initial value 0xFF.*

The polynomial for 2 byte CRC is $X^{16} + X^{12} + X^5 + 1$*. Initial value 0xFFFF."*

As it has been said before, CRC is calculated over a bit string which is not multiple of 8 (due to the Packet Control Field). This is unfortunate not only because it makes it compulsory to work at a bit level (which consume more resources) but because CRC functions available on the internet work at a byte level which compels this project to have its own CRC calculation function.

This function has the following characteristics:

Arguments:

- The bit string from which the CRC will be derived.

- An integer regarding the CRC's length.

Return:

- The resulting CRC's bit string.

The CRC's calculation procedure has been deeply analysed and can be found in the bibliography. Although some modifications can be added to this procedure, it basically consists on performing an XOR operation between the message and the polynomial in every iteration until you get the desired CRC length. The polynomial degree must equal the desired CRC bit length. In this case, an initial step is added to this process, which is performing an XOR operation between the message and an initial bit string which is going to be 0xFF for the one-byte CRC and 0xFFFF for the two-bytes CRC. The following example will provide a better understanding of how the function works.

This is a real packet sent by a transmitter:

10110010101100111011010000000111000000000101101000

3-bytes address (101100101011001110110100) | Packet Control Field (000001 11 0) | Message (000000001) | CRC (01101000)

Since the CRC is one-byte length, the polynomial $X^8 + X^2 + X + 1$ (100000111 converted to bit code) will be used coupled with an initial value of 0xFF (11111111 converted to bit code) as it has been mentioned before. The CRC is calculated over the whole packed (excluding the CRC itself), therefore, the CRC is calculated over the bit string: 101100101011001110110100000001110000000001. In order to perform the calculations correctly, eight "0" bits need to be appended to the end of this bit string which will end up being the CRC. Taking all these into account, the next steps need to be followed in order to obtain the CRC:

1. Align the initial value with the first bit of the given bit string and so on. Perform an XOR operation between the bits in the same column. The rest remains the same.

```
10110010101100111011010000000111000000000100000000
11111111
------------------------------------------------------------------------------------
01001101101100111011010000000111000000000100000000
```

2. Align the first bit of the polynomial bit string with the first "1" of the resulting bit string and perform the same XOR operation as in step one.

```
01001101101100111011010000000111000000000100000000
 100000111
------------------------------------------------------------------------------------
00001100011100111011010000000111000000000100000000
```

3. Iterate over step 2 until all the bits from the resulting bit string are “0” excluding the last 8 bits. These are the last two iterations.

```
0000000000000000000000000000000000001100000100000
                                    100000111
0000000000000000000000000000000000000100001010000
                                     100000111
0000000000000000000000000000000000000000001101000
```

The full CRC calculation is available in annex G and the CRC function in annex A.7.

7.5.4. Message extraction

Since there is no information about the incoming packets apart from the packet structure and the first three bytes of the address, a smart play is needed in order to finally get the correct message.

Firstly, the packet must be located among the large string of bits that have been recorded in the FIFO. Since the FIFO will start with the fifth byte of the packet (In this example the first four refer to the firsts address’ bytes), the problem lies in finding the end of the packet. As has been explained before, the CRC occupies the last bits of the packet, therefore, if the CRC is found, the packet will be located. Unfortunately, the CRC is unknown and it cannot be calculated since the packet has not been delimited yet. Besides, the CRC length is also unknown.

On the bright side, there is only one combination of packet length and CRC length that would make the CRC from the packet be equal to the CRC calculation over the packet (excluding the CRC). It would be a hard work to try all the combinations manually, fortunately it is easy for a computer to do this task.

Now that the Packet has been delimited, it is easy to locate the end of the message (where the CRC begins). Nevertheless, the beginning of it is not that simple to find. The reader might think that the beginning of the message can be derived since the length of the message is contained in the Packet Control Field. However, this section of the packet cannot be located since the address length is still unknown. Notwithstanding this fact, the length of the message is still there, somewhere inside the packet, and it has a fixed length of 6 bits. At this point, it is easy to notice that the same procedure used in the preceding paragraphs can also be applied in this case.

The process would be the following:

- Choose a payload length between 1 and 29
- Locate the position where the payload length should be (inside the Packet Control Field).
- Compare the chosen length with the bits where the payload length should be.
- If both numbers are the same, the payload length has been found. Otherwise, choose

the following number and restart the process.

With the payload length we can easily assign every bit to its corresponding section. Now, not only the message can be extracted but also the whole address so that the user can distinguish the messages by its transmitters. Moreover, the PID (contained in the Packet Control Field) is also available and its use will be explained in the following section.

7.5.5. PID. Avoiding retransmissions

In a normal transaction, the transmitter sends the same message several times and then changes to the receiving mode and waits for an acknowledgement packet from the receiver. If no acknowledgement is received, the transmitter restarts the process again and again until it receives the acknowledgement packet. The receiver waits for the message, and only when it is validated, changes to the transmitter mode and sends the acknowledgement packet to the transmitter and then turns back to the receiving mode. Since the receiver can easily receive another retransmitted package with exactly the same information as the one that has been already received, the packet must have something to differentiate a new packet from a retransmission. Comparing the message is not an option as some transmitters may be sending the same message over and over again until something changes. The solution in this case lies in the two PID bits. Every retransmission has the same combination of this two bits. The chip keeps the combination of the last message received. However, this is not enough to discard a packet since other devices could be sending different information with the same PID as another couple of packets that are being retransmitted. Therefore, not only the PID is compared with the new incoming message but also the CRC. That ensures that every new message is adequately handled and no duplicated messages are captured by the NRF24L01.

This packet transaction handling is automatic when enabling Enhanced ShockBurst. Unfortunately, this feature must be disabled to provide this chip with a Promiscuous Reading mode. Nevertheless, this automatic handling can also be manually applied (with software) since in this mode the PID is available as well as the CRC. In order to do this, the following process has been applied:

- Once the packet sections have been determined, the PID and the CRC from the packet are compared with the corresponding ones from the last packet received. In case they are different, the packet is automatically accepted.
- If the packet is accepted, its PID and CRC are recorded to be compared with the following packet.

7.5.6. First try-outs

This section is going to tackle all the problems encountered when putting all the previous points into practice. This is, explaining the problem and providing the solution that has been implemented.

Problem:

The first time it ran, the program stopped working when validating the message. This was due to the large amount of calculations that the main thread had to do when validating the message.

Fig. 7.20 Frozen screen when trying to validate the packets. Own source.

Solution:

The development of a new thread that executes these calculations simultaneously. This thread named packet_validation, is called every time the the FIFO receives something and, the main aim of this thread is to determine if the bitstring that the FIFO has captured is a real packet or just noise. This thread calls the *crc_()* function several times so it has to performe a large number of operations.

Problem:

The new thread is not fast enough to tackle all the noise. The thread is reinstanciated before it actually finishes executing the code.

Solution 1:

Up to 10 threads are instanciated to deal with all the noise. This threads are instanciated inside a list so that its elements are constantly recycled. This gives the threads enough time to perform its calculations before they are recycled.

Solution 2:

This mode was consuming a great deal of resources which lead this project to an optimization process. Since the crc_ () is the function that more times is executed by far and the one that takes more time to be executed, it is sensible to try to enhance its efficiency.

Luckly, there was a lot of room for improvement since the function was developed, in such a way that the steps in between the calculations could be easily printed to fix any possible error. Both the old and the new function are available in annex A.7.

This functions' performance was evaluated in terms of timing. Since the packet_validation() thread will normally be executed because of the noise, the function will run all the loops till the end. As will be explained later, validating a noise packet would be equivalent to running 58 times (29 times every CRC length) a 17 bytes packet. The reason why this test has not been performed within the application is because it was considered necessary to isolate the problem so that non external influences could afect the final results. The test was performed 10 times to ensure the reliability of the results.

RESULTS	
crc_func (old version) average	6,624 s
crc_ (optimized version) average	1,0428 s
Time improvement (%)	84,26%

Table 7.5 Time test results. Own source.

7.5.7. Automatic_mode class

This section gives an insight over the methods that make this mode do the trick. The code regarding this class is available in annex A.3.

7.5.7.1. apply_new_parameters

Since this method has been explained in other modes and no further information is necessary, here is the NRF24L01 configuration for both the transmitter and the receiver. Note the flexibility from the transmitter's side.

Input Settings

Air rate	Same for the receiver and the transmitter
Channel	Same for the receiver and the transmitter
Pipe	Not relevant
Pipe address	Same first three bytes for the receiver and the transmitter

Register Map configuration

Register	**Receiver**	**Transmitter**
00	0b0 - (CRC disabled)	0x0C
01	0b0 – Enhanced ShockBurst disabled	Not relevant
02	Enabled at least 1 pipe	Not relevant
03	0b11 – 3 bytes long	Address width (related to register 10)
04	Not relevant	Not relevant
05	Same for the receiver and the transmitter	Same for the receiver and the transmitter
06	Same for the receiver and the transmitter	Same for the receiver and the transmitter

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07	Not relevant	Not relevant
08	Not relevant	Not relevant
09	Default	Default
0A	One of these registers must fit the last 3 bytes introduced in the transmitter register 10	Not relevant
0B		Not relevant
0C		Not relevant
0D		Not relevant
0E		Not relevant
0F		Not relevant
10	Not relevant	Last 3 bytes introduced must equal one enabled RX pipe address (notice LSB is written first)
11	The pipe that is going to be used must have a 32 bytes payload width	Not relevant
12		Not relevant
13		Not relevant
14		Not relevant
15		Not relevant
16		Not relevant
17	Default	Default
1C	Not relevant	Not relevant
1D	Not relevant	Dynamic Payload Length Enabled

Table 7.6 Registers' configuration. Own source.

7.5.7.2. read()

Once the RX FIFO captures a possible packet, this method is called. If Focus or File download mode are disabled, the data is manipulated in order to obtain the full packet. This means joining the first 3 bytes from the address to the rest of the packet. Then, the packet validation thread is called. In future sections will be explained what happens when those modes are enabled.

7.5.7.3. packet_validation class

Although this is not a method of the `AutomaticMode` class, it is worth explaining this thread in order to follow a logic sequence of actions.

This class is eventually called by *read()* and automatically executes its run method. This method validates the packet as has been explained in the preceding sections. This means trying different packet length and CRC length until one of them fits with the calculated CRC. It also goes through a similar process in order to find the payload length and therefore, the address length. It finally sends back all the extracted information from the packet and presents it to the *filter_duplicities()* method from `AutomaticMode` class.

7.5.7.4. filter_duplicities()

As obvious as it seems, this method filters the retransmission packets so that no duplicated messages are displayed in the text browser. This is done by comparing the PID and the CRC from the last message with the PID and CRC from the current packet.

If the message passes this filter, it will be sent to *add_to_record()*, which will display the message on the screen.

7.5.8. Example

Transmitter's code for this example is available in annex D. Let's take a look at the final Automatic mode layout:

Fig. 7.21 Final Automatic mode layout. Own source.

Only 3 parameters are to be set in order to receive the desired packets. In fact, not even the full length of the address needs to be provided. Just the first 3 bytes are necessary (although more bytes can be provided). In this example, packets starting with the b3 b2 b2 are going to be caught. As always, parameters need to be applied by clicking on “Apply new parameters” before clicking on the “Listen” button.

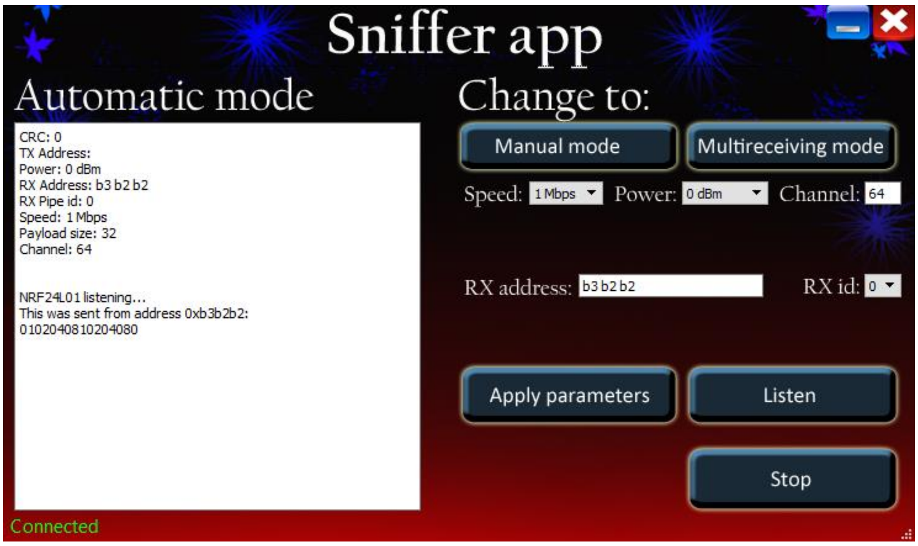

Fig. 7.22 Message reception. Own source.

7.5.9. Extra functionalities

The testing of this mode revealed that when using a high payload length (near 29 bytes), the app needs up to 10 seconds to process all the packet. This is due to the fact that a great deal of calculations need to be performed before reaching the correct combination of CRC length, payload length and address length coupled with the fact that other validations can be running at the same time. The following functionalities have been implemented in order to give an optimised solution to this problem. These functionalities, although spread over the whole code, do not affect other methods behaviour unless certain conditions are met or the user specifies it as will be shown.

A new method has been created to provide what is going to be called from this point onwards as "fast reception":

fast_reception()

This method takes the configuration information from the transmitter's packet and configures the receiver accordingly so that all the packet extraction can be processed by the NRF24L01 which is going to be way faster than keeping the Automatic Mode on. It is important to draw attention to the fact that this change of configuration prevents the receiver from receiving information from other devices but just for a brief period of time, in which the great majority if not all the packets will be sent by the transmitter.

These method is the base upon which the following features will be built.

7.5.9.1. Fast file download

This functionality is automatically enabled when the receiver receives a file. Every file sent to the receiver must be encapsulated in between two messages: "text fileXXXX" and "end file", where "XXXX" is the size of the file. When a text file is being received, *fast_reception()* method is called. While the file is being downloaded, the app pops up a saving file window where the user will be able to select the file location as well as its name. At the same time, the text file will periodically provide information about the percentage of file that has been downloaded. Once the file has been downloaded, the app will change back to the Automatic mode and will show a message confirming this fact. The download will be available for the user to be accessed. add_to_record() method is in charge of storing the file in this case. read() method translates the bytes of the message into letters and symbols using ascii decoding. The files and functions that have been used to translate the text file into bytes and to send the packets are available in the bibliography[

Example:

Figure 7.23 shows the saving window that pops up when a file is received.

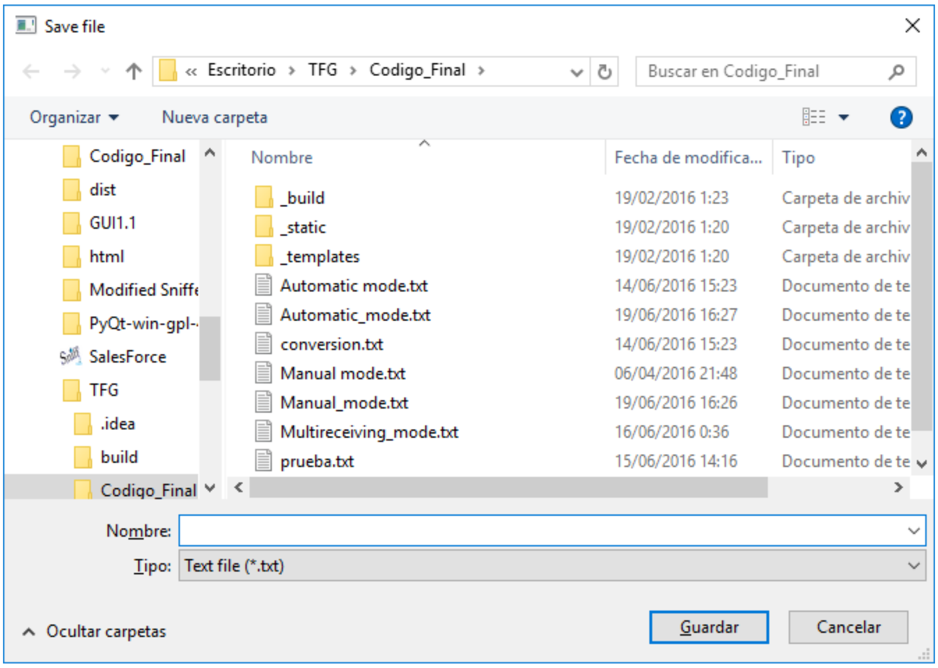

Fig. 7.23 Window opened when a file is received. Own source.

The main window shows the progression of the download in real time.

Fig. 7.24 Downloading file. Own source.

The process finishes when the end file message is received.

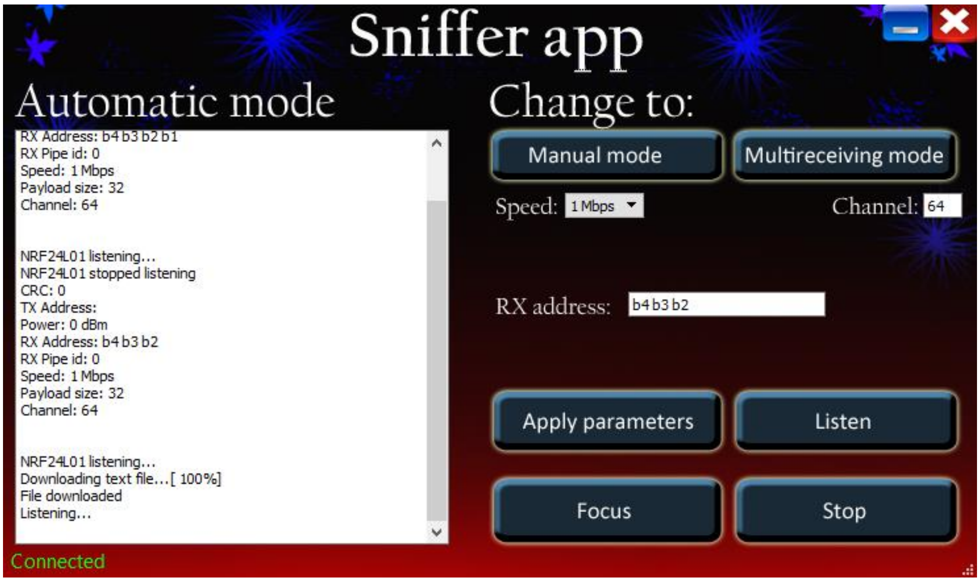

Fig. 7.25 Downloading file. Own source.

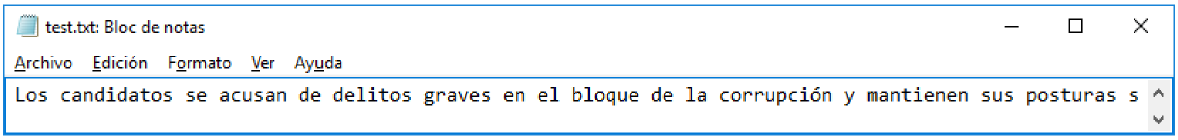

Fig. 7.26 Downloaded file. Own source.

7.5.9.2. Focus

By clicking the “Focus” button, the app will focus its attention on the transmitter that sent the last packet using fast reception. This allows almost instantaneous message reception taking profit of the already built *fast_reception()* method. The messages will appear one after the other since there is no point in providing information about the address as will be the same for every message received.This feature is disabled when clicking “Focus” again. It is worth mentioning that this feature has been adapted to be compatible with a wireless keyboard. Therefore, the messages that will appear on screen after clicking on focus will be converted regarding the keyboard code.

Example:

Once the first message is received the user can click on “Focus” to focus on the last address received. Then the application is going to translate every byte received from that address and concatenate the messages. Every letter that the user types with the keyboard will appear on the screen almost instantly.

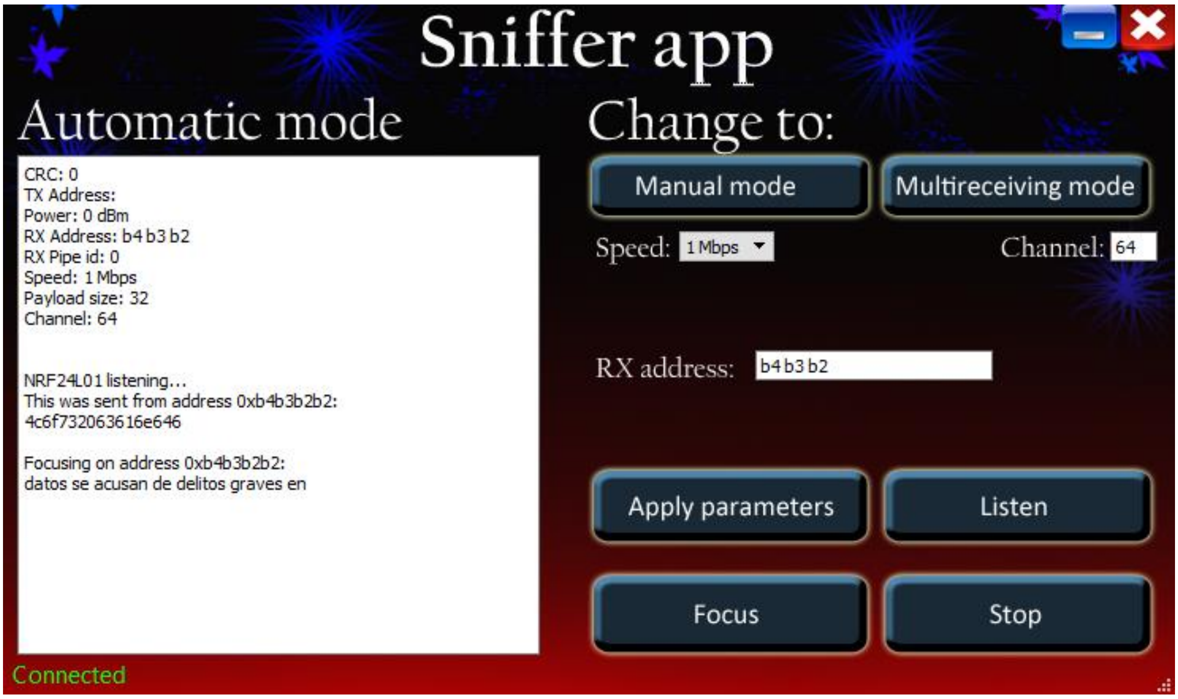

Fig. 7.27 Downloading file. Own source.

7.6. Tests

These are the tests that have been performed to ensure the well-functioning of these modes.

7.6.1. Manual mode

Checking all the parameters available in the user interface. Payload limits (32 bytes) will also be checked. Since this implementation is identical in every mode, this test will not be applied in the other modes:

Fig. 7.28 Message reception. Own source.

Fig. 7.29 Checking receiver parameters. Own source.

Fig. 7.30 Checking transmitter parameters. Own source.

7.6.2. Multireceiving mode:

Checking all pipes and sending two messages at the same time.

Fig. 7.31 Checking multireceiver parameters. Own source.

7.6.3. Automatic mode

Checking all address length possibilities from the transmitter and the receiver side. At the same time, the CRC has been changed as well. Also check that messages are also received when sending at the same time:

Fig. 7.32 Receiver address length: 3 bytes – Transmitter address length: 3 bytes – CRC: 2. Own Source.

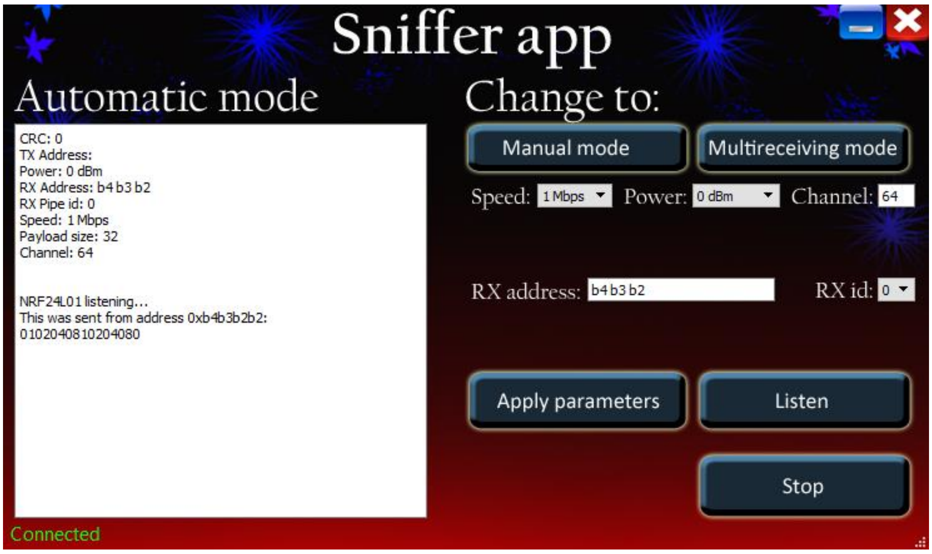

Fig. 7.33 Receiver address length: 3 bytes – Transmitter address length: 4 bytes – CRC: 1. Own Source.

Fig. 7.34 Receiver address length: 3 bytes – Transmitter address length: 5 bytes – CRC: 2. Own Source.

Fig. 7.35 Receiver address length: 4 bytes – Transmitter address length: 4 bytes – CRC: 1. Own Source.

Fig. 7.36 Receiver address length: 4 bytes – Transmitter address length: 5 bytes – CRC: 2. Own Source.

Fig. 7.37 Receiver address length: 5 bytes – Transmitter address length: 5 bytes – CRC: 1. Own Source.

8. Compatibility

The aim of this project is to create a python application. Nevertheless, this leads to a compatibility problem when someone tries to run the app in Microsoft Windows OS and does not have python, or has python but does not have the required modules. Therefore, some efforts have been made in the direction of finding a tool to convert the python application into an exe file that can be directly executed from any Microsoft Windows OS. The reason for doing this is to accomplish one of the main objectives of this project, which is, preventing the user from any contact with programming, and that includes downloading python and its modules.

After some research a tool was found to convert python files into a Windows executable. This tool, named *py2exe*, permits this conversion [11]. It includes all the necessary modules in a folder together with other necessary files that support this executable file. More information about how this conversion is performed can be found in the bibliography.

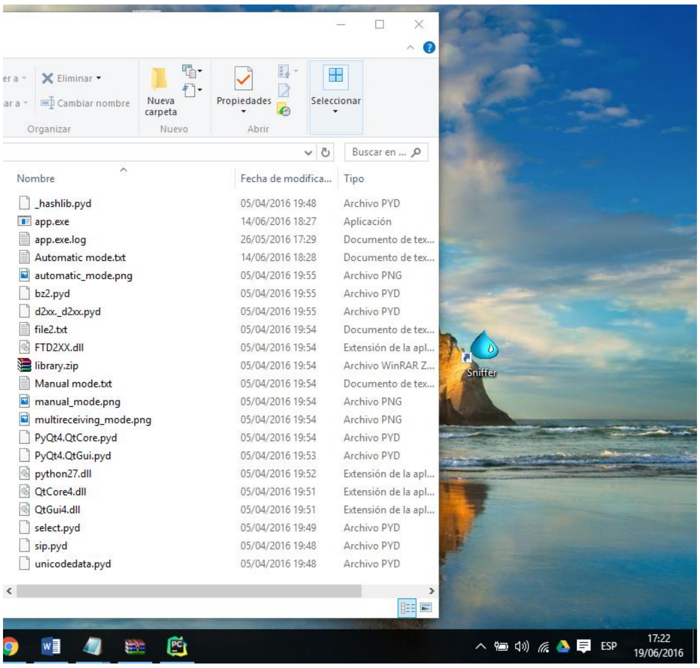

Fig. 8.1 Folder where the .exe file is located and the direct access to the app on the Desktop. Own Source.

9. Future Works

Since this project has focused its efforts on how this sniffer can receive information, there are a few aspects that have not been tackled and would be worth of further study. These are some examples:

- This sniffer can, with the app, get the configuration settings from packets sent by different devices. It would be interesting to give the app the possibility to configure itself based on received messages. Then, it could reconfigure different devices with different configurations that are not receiving each other's packets, into one single configuration and allow these devices to catch each other's packets.

- The acknowledgement packet has not been tackled in depth since this project, although includes a message sending feature, is mainly focused on the reception side. Therefore, it would be interesting to send several packets waiting for the acknowledgement packet each time so that no errors could arise in the communication process.

- Other platforms and programming languages could be used in order to give this sniffer more flexibility. For instance, with the development of an app for android, the user could even send pictures or recordings through these devices.

- Delving into the last point, it would be interesting to connect somehow this boards to the speakers' cable and try to send music through a smartphone or tablet.

- The NRF24L01 can be used in the development of a wireless peripheral such as a mouse, a playstation controller or even the smartphone could be used to control certain actions on the computer.

10. Environmental footprint

Although this is a software development project, hardware parts of this project need to be analysed in terms of recycling and in the case of the NRF24L01, RF consequences on humans must also be taken into account.

According to Electronics TakeBack Coalition [12], "Over 1,000 materials, including chlorinated solvents, brominated flame retardants, PVC, heavy metals, plastics and gases, are used to make electronic products and their components—semiconductor chips, circuit boards, display panels, and disk drives. […] About 40% of the heavy metals in landfills, including lead, mercury and cadmium, comes from electronic equipment discards". These products are very damaging for the environment and need to be properly recycled. Therefore, once the user has exploded the first two 'R's (Reduce and Reuse) [13], the recycling process takes place. In order to do so, the user must find a "Punto limpio". Ecolec foundation has all these points mapped over the whole country [14].

According to the "Real Decreto 1066/2001" [15], There is mainly 1 restriction for the frequency range between 10 MHz and 10 GHz (in which our sniffer works). The average body SAR must not be greater than 0,08 W/Kg. Considering a person whose total body mass is below average (~50 Kg) and assuming this person is absorbing all the RF waves, if the NRF24L01 was working in a transmitter mode at maximum power (1 mW) the SAR would be 0,00002 W/Kg. Therefore, it can be assured that this device will never be harmful to humans in terms of RF.

11. Costs and time planning

COSTS			
	Quantity	**Cost/Unit (€/u)**	**Total item cost(€)**
C232HM-DDHSL-0	1	41,31	41,31
NRF24L01+	1	3,99	3,99
Pack Open18F4520 Package B (board, PIC18F4520, nRF24L01+ module, connexion cables, peripherals)	3	73,75	221,25
		TOTAL	266,55 €

TIME PLANNING			
	Hours	**Cost/hour (€/h)**	**Total cost (€)**
Previous study	75	60	4500
GUI building	50	60	3000
Manual mode	25	60	1500
Multireceiving mode	5	60	300
Automatic mode	50	60	3000
Trials and testing	75	60	4500
Documentation	100	60	6000
TOTAL	380	**TOTAL**	22800 €

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Conclusions

The aim of this project was to build a python application capable of interacting with a NRF24L01 to act as a sniffer, providing feedback from RF communications between different devices. This main objective has been successfully achieved and other objectives focused on that direction have also been successfully implemented within the app. Here is an overview of the relevant points regarding this project coupled with some problems or difficulties that have been encountered and how they have been tackled:

- Standard communication between several boards have been stablished (Manual and Multireceiving mode).
- The chip allows to catch packets that match their first 3 bytes and saves almost the whole packet inside the RX FIFO which gives free rein to packet manipulation. This operation has a 28 bytes' payload limitation as opposed to the 32 bytes in a regular communication. This is because almost the whole packet is saved in the RX FIFO rather than just the message.
- Packet treatment procedures such as CRC calculation, message extraction and retransmissions removal can be processed by the PC.
- These latter points allow this application to abuse from the CRC packet validation and extract the message from that packet together with some relevant information about the transmitters configuration.
- The last point has been proved to be a bit slow when trying to extract long messages (near to 29 bytes).
- This problem has triggered the creation of 2 functionalities (Fast file download and Focus) that have appeared to be way faster, losing very little flexibility thanks to the fast reception function.
- The system NRF24L01 - USB/MPSSE cable – computer can properly work as a sniffer.
- A completely customized GUI has been built with python modules and has been converted into an executable file for Microsoft Windows OS. This provides easy access to the application without having to download either python or any of its modules.

To conclude, it is worth mentioning that this application exploits all the resources that this board provides, taking it to whole new level where not only the message can be acquired from almost any packet, with no more information than the first 3 bytes, but also relevant information about the transmitters configuration, which is of paramount importance for the purpose of this application.

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