ET4394 Wireless Networking 2015-16
GNU Radio Assignment

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Contents

1 Introduction

There are registered, but unused frequency bands that could be used by another service. A system that is capable of first detection and then sending over an empty frequency band has advantages over a *fixed* system. It is better a guaranteeing performance when frequency bands for the *fixed* system are used a lot. The television frequency bands are good candidate frequency bands for a cognitive radio, i.e., a radio that is intelligent and can be programmed and configured dynamically to a specific frequency[1].

1.1 DVB-T

Digital Video Broadcasting Terrestrial, DVB-T, i.e., the broadcasting of digital television threw ground stations (terrestrial), uses the frequencies in the spectrum from $478Mhz$ to $862Mhz$ and consists of multiple bands. Each band is $8Mhz$ wide and can transmit multiple TV and radio channels by making use of *QPSK*, *16-QAM* or *64-QAM* encoding. See table 1 for the frequencies used in the Delft area[2].

MUX Operator	Channel Number	Center Frequency (Mhz)
RTS Bouquet 1	52	722
NTS1 Bouquet 2	49	698
NTS2 Bouquet 3	57	762
NTS3 Bouquet 4	24	498
NTS4 Bouquet 5	27	522

Table 1: DVB-T frequencies in the Delft area

Other cities can use the same (DVB-T) channels and in order to collisions the effective radiated power, *ERP*, is regulated. In this report a method is being described to detect if an DVB-T channel is empty or not.

Section 2, *Project Description* briefly states the objective of this assignment. Section 3, *Approach* will propose two solutions: **Solution 1** that requires few resources and **solution 2** that is more accurate but requires more resources. Section 4, *Implementation*, tells how the solutions are implemented using *GNU Radio*. *GNU Radio* is a software defined radio program that can manipulate and process radio signals. In Section 5, *Results & Analysis*, the results of the measurements are presented and discussed. Section 6, *Conclusion*, gives a brief conclusion.

2 Project Description

The objective of this assignment is to develop a system that is capable of detection signals in the DVB-T signal range. Propose (several) techniques to detect if a DVB-T channel is present and compute the chance misdetection (p_{md}), i.e., the chance of detecting a signel when there is none and false alarm (p_{fa}), i.e., the chance of not detecting a signal when there is one present.

3 Approach

The power spectrum of a DVB-T channel is very flat, this makes it ideal for being detected. See figure 1: A basic system consists of a source outputting I/Q values that are processed by a FFT. The samples coming out of the FFT are complex, e.g., $a + bi$ and are converted to "power" samples to be able to analyse them properly, i.e., $P = a^2 + b^2 = \text{abs}(a + bi)^2$. Depending on the type of FFT some dimensioning needs to be done to present the results in dB. This assignment focuses on 2 solutions, one more accurate but more expensive and the other less accurate and less expensive.

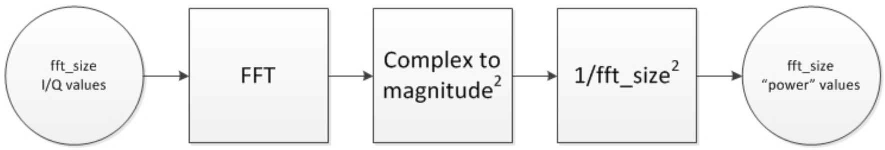


Figure 1: Basic blocks needed for processing the signal

In this assignment the fft_size will be 1024 and the sampling frequency $2.048MHz$.

3.1 Solution 1

Assuming that the power spectrum of the DVB-T band is flat you could just take one "power" sample and compare it to a well chosen threshold and decide if there is a signal present or not. This may be a unreliably since the signal may not be as predictable as you think.

3.2 Solution 2

Assuming that the power spectrum of the DVB-T band is not flat you could take the mean of all the "power samples" and compare that with a well chosen threshold. Any irregularities in the "flat" power spectrum will be filtered out

Trade-off Note that solution 1 is less accurate but costs less resources and is faster while solution 2 is more accurate but is more expensive and takes more time. Depending on the threshold, p_{fa} and p_{md} a decision has to be made.

3.3 Detecting Scheme

See figure 2, here you can see the basic detection scheme needed. After receiving the signal it needs to be processed, figure 1 and the first part of section 3, *Approach*, already showed how to process the data for solution 1. For solution 2 you also need to take mean value of all the "power" samples.

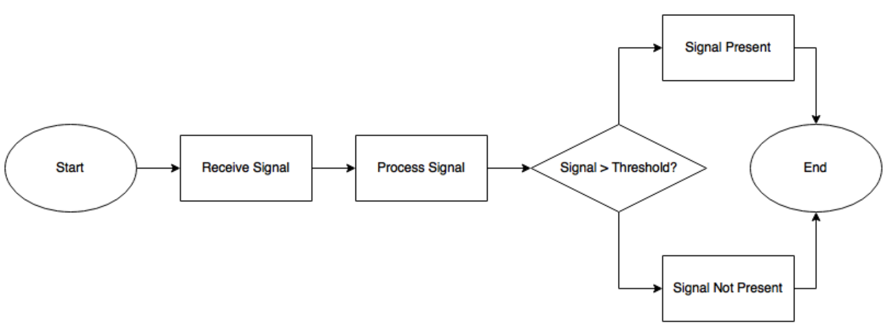


Figure 2: Basic Detecting scheme

How to determine p_{fa} and p_{md}? First you need to select, and be sure, two DVB-T channels: one used and one unused. To determine p_{fa} keep track of the number of times you get **signal present**

and **signal not present** for an used DVB-T channel, p_{fa} is then approximate:

$$p_{fa} \approx \frac{\#\textbf{signal not present}}{\#\textbf{signal present} + \#\textbf{signal not present}}$$

To determine p_{md} keep track of the number of times you get **signal present** and **signal not present** for an unused DVB-T channel, p_{md} is then approximate:

$$p_{md} \approx \frac{\#\textbf{signal present}}{\#\textbf{signal present} + \#\textbf{signal not present}}$$

Note that p_{fa} and p_{md} will yield different values at different thresholds!

4 Implementation

For this assignment a RTL2838 dongle is used as a receiver. After some internal processing it outputs I/Q samples needed for the detecting scheme. First the used blocks are explained and the scheme of solution 1 and 2 are briefly discussed.

Moving Average Block This block has 3 parameters: `Length`, `Scale` and `Max Iter`. The output of this block is equal to

$$\sum_{i=0}^{\text{Length-1}} x_i * \text{Scale}$$

where x_i is a sample on it's input. As you can see it is necessary to divide the ouput of this block by `Length` to generate an average value for the past `Length` samples. `Max Iter` is a setting to avoid numerical instability for float and complex and is in all our Moving Average blocks set to `Length`

Determine p_{fa} and p_{md} See figure 3 or 4. The Moving Average block with Length $= 1M$ and the Devide after it are used to determine p_{fa} and p_{md} because

$$p_{md} \approx \frac{\textbf{\#signal present}}{\textbf{\#signal present} + \textbf{\#signal not present}} = \frac{\sum_{i=0}^{\text{N-1}} x_i}{N}$$

where $N = \textbf{\#signal present} + \textbf{\#signal not present}$ and x_i is either 1 (signal present) or 0 (signal not present). Note that $\sum_{i=0}^{\text{N-1}} x_i$ only affects 1 (signal present).

The same analysis holds for p_{fa}:

$$p_{fa} \approx \frac{\textbf{\#signal not present}}{\textbf{\#signal present} + \textbf{\#signal not present}} = 1 - \frac{\textbf{\#signal present}}{\textbf{\#signal present} + \textbf{\#signal not present}} = 1 - \frac{\sum_{i=0}^{\text{N-1}} x_i}{N}$$

where again $N = \textbf{\#signal present} + \textbf{\#signal not present}$ and x_i is either 1 (signal present) or 0 (signal not present). Note the Subtract block and the Constant 1.

See table 2 for more information regarding other blocks used in the schemes.

Block Name	Description	Parameters
RTL-SDR Source	Collect I/Q samples	Sample Rate: $2.048M$ Samples/s RF Gain: $20dB$, IF Gain: $0dB$ Bandwidth: $0Hz$ Frequency: $474e6 + (channel - 21) * 8e6$
Stream to Vector	Collect fft_size samples and create a fft_size length vector	fft_size: 1024
FFT	Compute the FFT Generate "FFT" samples	Sample Rate: $2.048M$ Samples/s fft_size: 1024
Complex to Mag^2	Generate "power" samples from "FFT" samples	
Log10	$P_{dB} = n * \log 10(P_{watt})$	n: 10
Threshold	Compare values to the threshold	Low: Threshold (variable) High: Threshold (variable)
WX GUI Number Sink	Displaying Numbers in the GUI	Sample Rate: $2.048M$ Samples/s
WX GUI FFT Sink	Displaying FFT in the GUI	Sample Rate: $2.048M$ Samples/s

Table 2: GNU Radio Block descriptions

4.1 Schemes

Figure 3 is the scheme for solution 1 and figure 4 is the scheme for solution 2. Note that in the scheme of solution 2 an extra Moving Average block is added, this is to calculate the mean of all the "power" samples. Figure 5 shows the GUI. Here $p\_1 = p_{md}$ in case of an unused DVB-T channel and $p\_0 = p_{fa}$

in case of an used DVB-T channel. `Strength` is the average power of the signal. The average function in the GUI as well as the (optional) moving average block calculate this. Note that in figure 5 0.00% should be 0% and 1.00% should be 100%

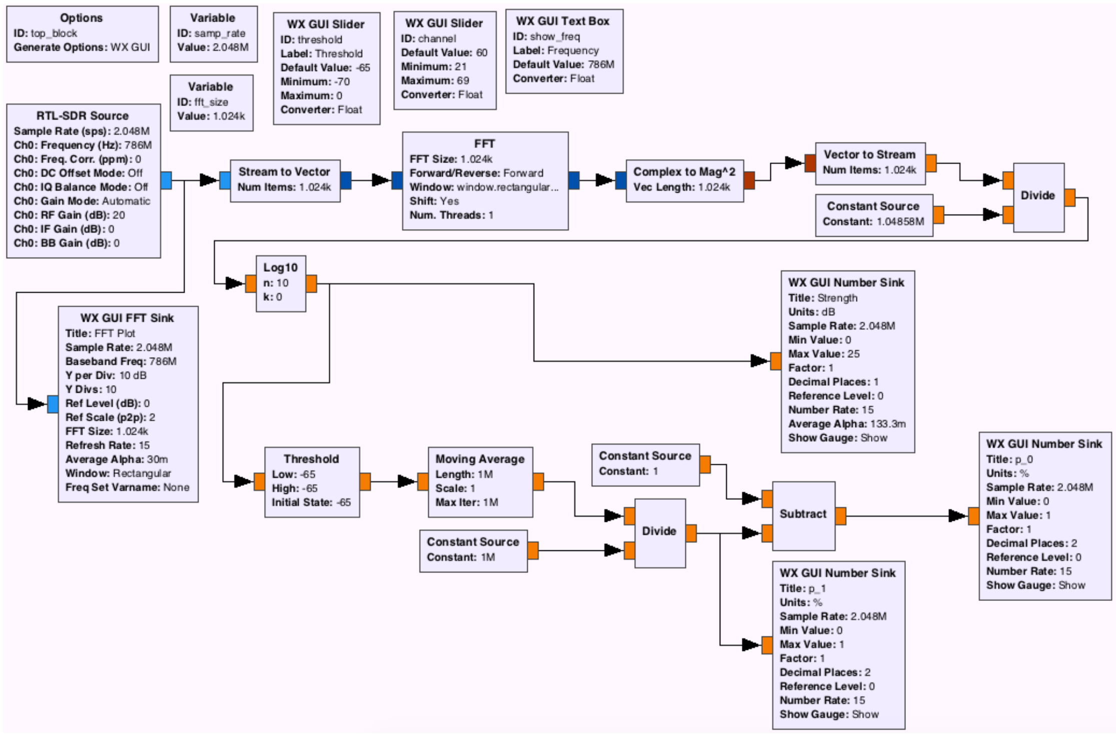


Figure 3: Scheme for **solution 1**

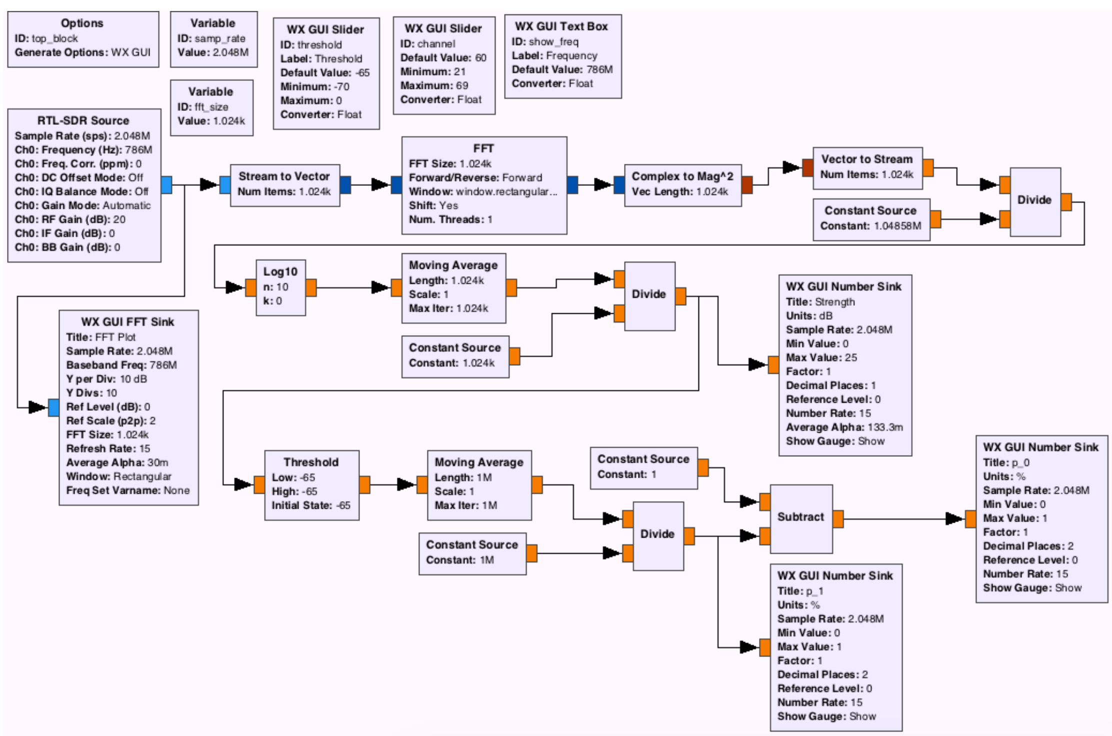


Figure 4: Scheme for **solution 2**

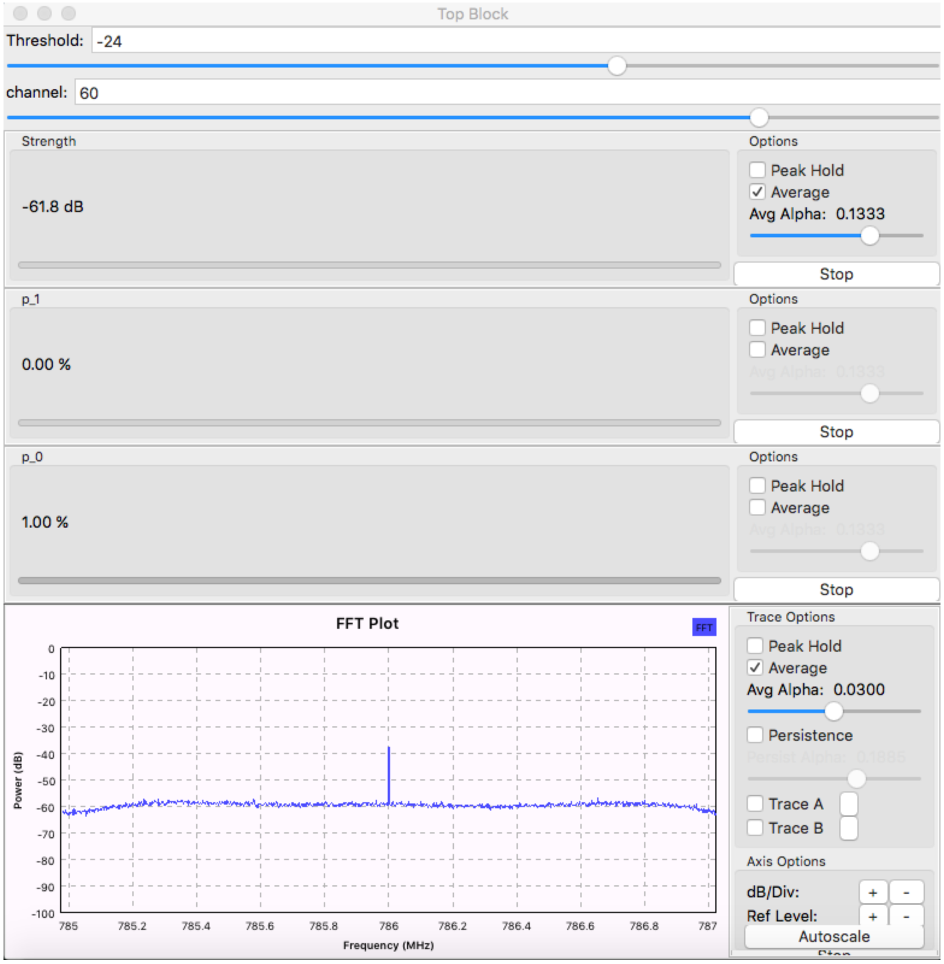


Figure 5: GUI for **solution 1** and **solution 2**

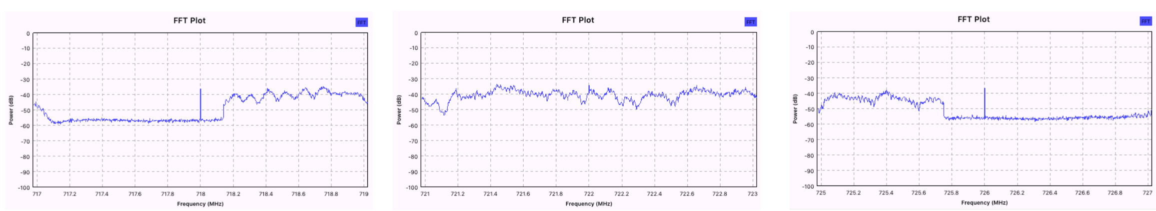
5 Results & Analysis

5.1 DVB-T channel

Figure 5(a), 5(b) and 5(c) show the start, middle and end of the used DVB-T channel 57 respectively. Because of the limited sample frequency of the RTL2838 dongle the spectrum only shows $2MHz$. As you can see the form of the signal is predictable and fairly flat. A way to measure the flatness is by looking at the standard deviation of the "power" samples. In this case the frequency was set to the center of the DVB-T channel. See table 3. To calculate this you take N "power" samples and process them in Matlab with the `std` command. All the std and mean values in the table are rounded.

DVB-T Channel	std (dB)	mean (dB)
24	7.1	-48.9
27	6.6	-43.6
49	5.8	-41.8
52	5.6	-41.5
57	7.0	-47.3
60	5.7	-64.7

Table 3: Standard Deviation (std) and mean for DVB-T channels 24, 27, 49, 52, 57 and 60



(a): start (b): middle (c): end

Figure 6: Form of a DVB-T channel

5.2 p_{md} and p_{fa}

First we need to define some variables:

- p^1_{md} is the chance of misdetection given a certain threshold and using **solution 1**
- p^2_{md} is the chance of misdetection given a certain threshold and using **solution 2**
- p^1_{fa} is the chance of false alaram given a certain threshold and using **solution 1**
- p^2_{fa} is the chance of false alaram given a certain threshold and using **solution 2**

Measurements has been done at the first floor of EWI (location 1) and in the Westerstraat in Delft (location 2). The figures 7, 8, 9, 10, 11 and 12 below show for each DVB-T channel p^1_{md} (location 1), p^2_{md} (location 1) and p^1_{md} (location 2) in case the DVB-T channel is unused and p^1_{fa} (location 1), p^2_{fa} (location 1) and p^1_{fa} (location 2) in case the DVB-T channel is used. Note that p^2_{fa} (loc 2) is not used because is it very similar to p^2_{fa} (loc 1) and would only add confusion.

5.3 Analysis Solution 1

The figures 7, 8, 9, 10, 11 clearly show that the reception was better at location 2. This can be caused by multiple factor such as antenna position, indoors or outdoors, weather, how close you are to send antenna and more. However if you look at figure 12 you see no difference, this was to be expected. The noise floor should be same and not be depending on your location.

When taking a closer look you can see that for low thresholds p_{fa} is almost 0 but p_{md} is almost 1, using such a threshold you would not be able to detect a signal because if the detector says "yes" you

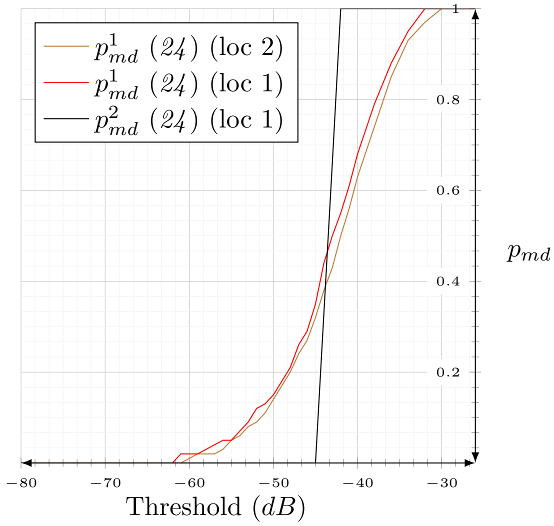


Figure 7: DVB-T Channel 24

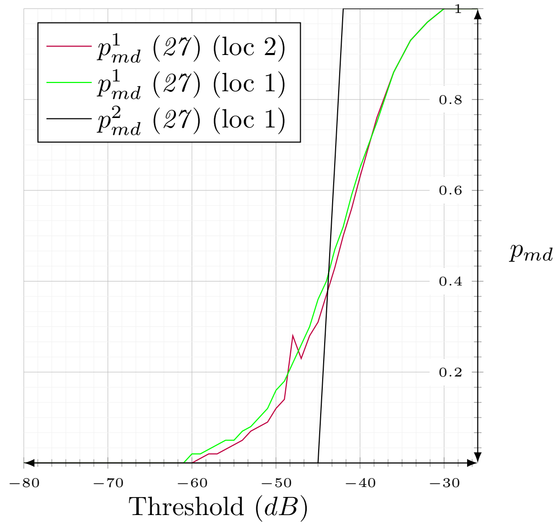


Figure 8: DVB-T Channel 27

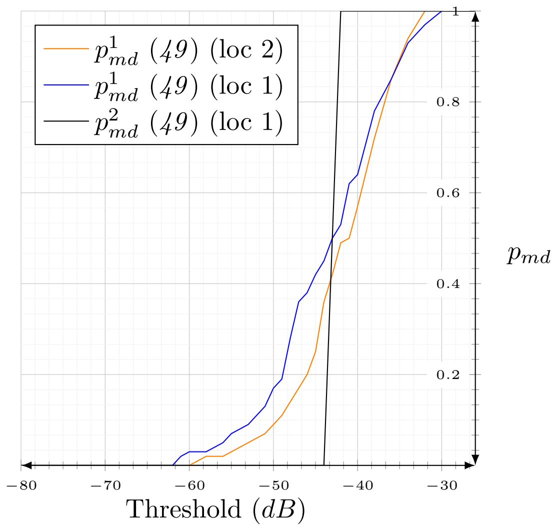


Figure 9: DVB-T Channel 49

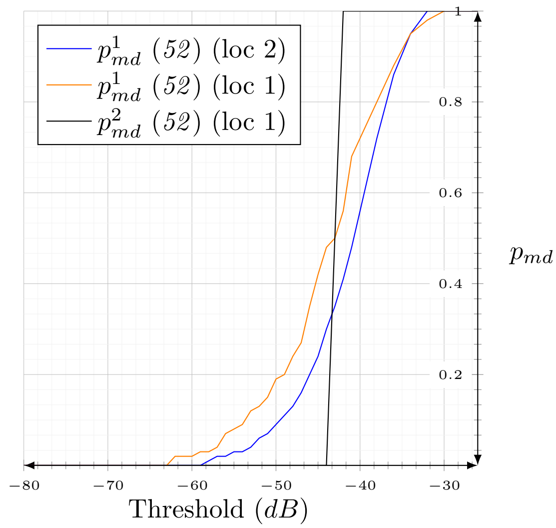


Figure 10: DVB-T Channel 52

are not sure if you are detecting the noise floor of an actual signal. When you choose a high threshold p_{fa} is almost 0 but p_{md} is almost 1, the detector is not able to detect any signal or noise floor and will always output 0, i.e., "This is not an used channel". If you use solution 1 an optimum threshold needs to be found that minimizes p_{fa} and p_{md}, this is shown in figures 13 and 14 for location 1 and location 2 respectively.

Choosing a threshold of about $-55dB$ will in both cases minimise the p_{fa} and p_{md} to around 0.1 but depending on your application you could pick another value.

5.4 Analysis Solution 2

In figure 15 you can see both solution 1 and 2 for an used and unused channel. There are many threshold points which result in $p_{fa} = p_{md} = 0$. This is because you decide using the mean of the "power" samples. Using solution 2 you can guaranty that your detector works without any flows, the only drawback is the longer sensing time which in return reduces the throughput.

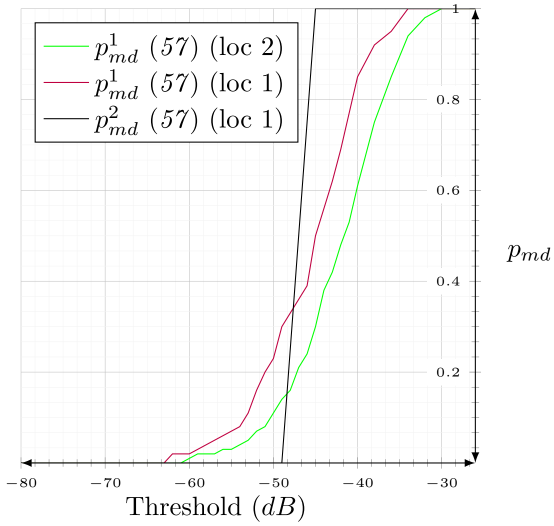


Figure 11: DVB-T Channel 57

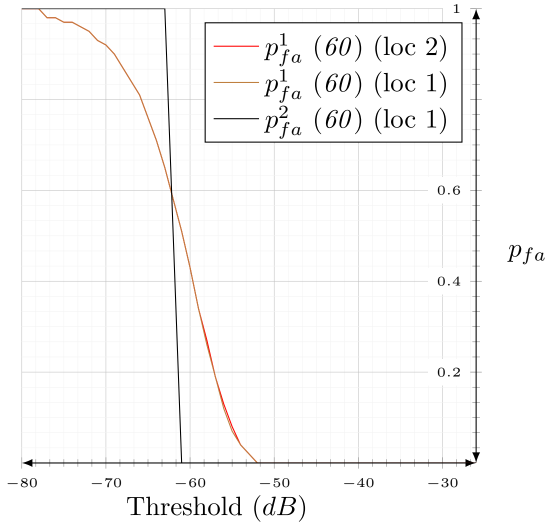


Figure 12: DVB-T Channel 60

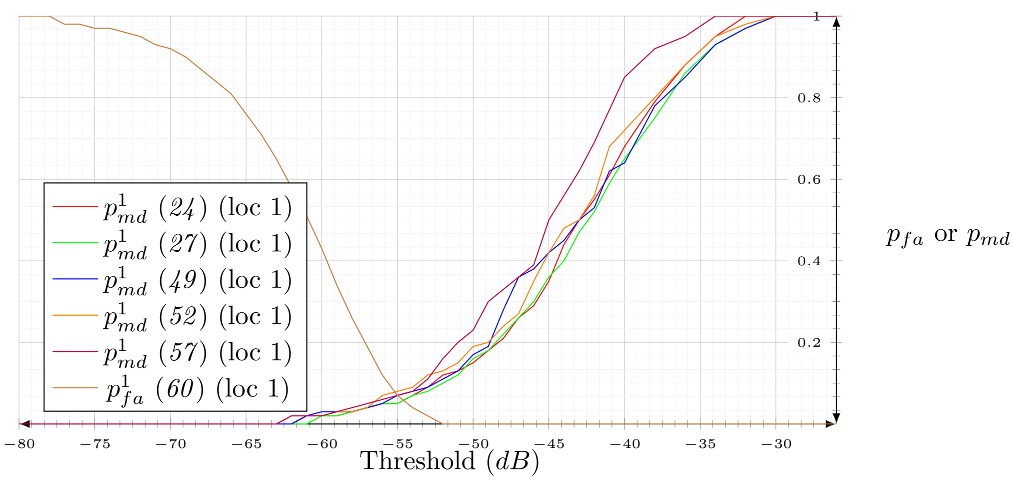


Figure 13: DVB-T Channel 24, 27, 49, 52, 57 and 60 (location 1)

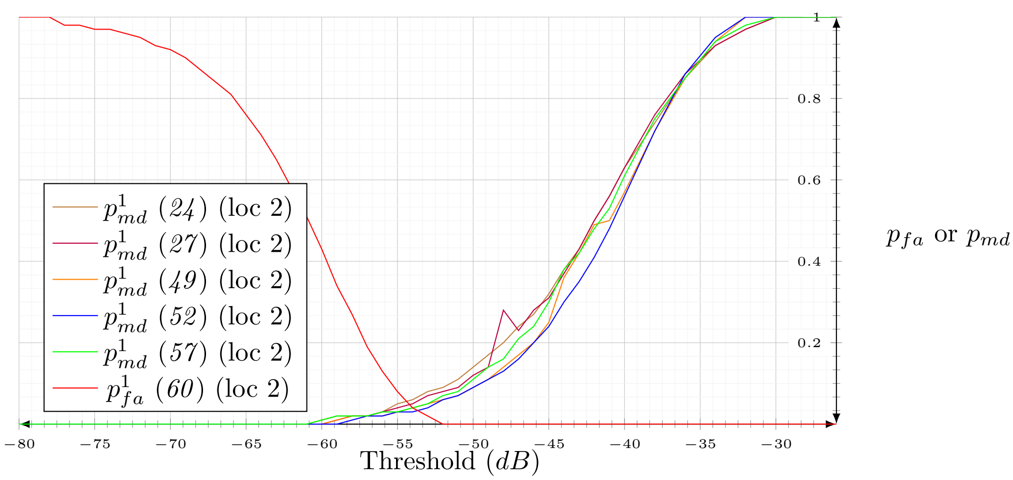


Figure 14: DVB-T Channel 24, 27, 49, 52, 57 and 60 (location 2)

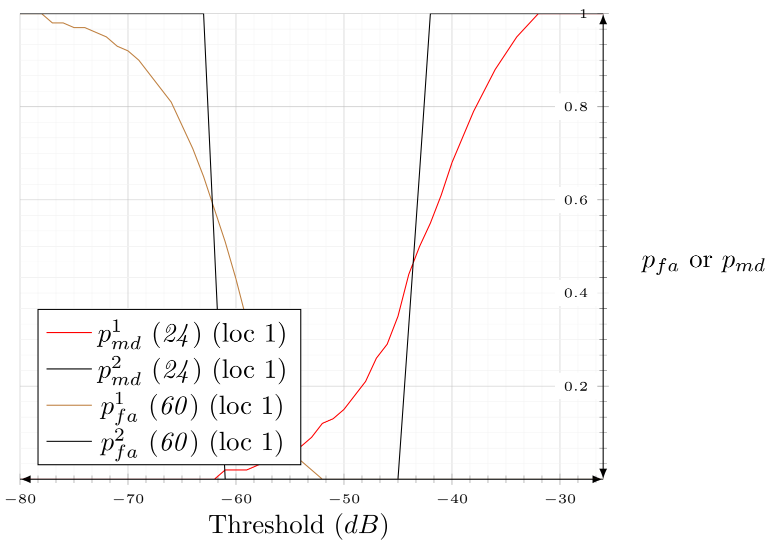


Figure 15: DVB-T Channel 57 and 60 (location 1)

6 Conclusion

Signal sensing can be challenging since a lot of chooses has to made. Having a better receiver with a lower noise floor results in a better p_{fa} and p_{md} at a higher cost, having more math intense processing decreases p_{fa} and p_{md} but increases the sensing time needed. Furthermore when choosing a solution 1 like option you have to determine the p_{fa} and p_{md} according to your application.

7 References

[1] Wikipedia. Cognitive Radio. Available at *https://en.wikipedia.org/wiki/Cognitive_radio*, April 2016.

[2] DVB-T. Available at *http://radio-tv-nederland.nl/dvbt/digitenne-kpntv.html*, April 2016.