Wireless Networking:GNU Radio

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May 8, 2016

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1 Introduction

In telecommunications, white spaces refer to frequencies allocated to a broadcasting service but not used locally[1].They are free of RF interference except for white Gaussian noise. National and international bodies assign different frequencies for specific uses, and in most cases license the rights to broadcast over these frequencies. This frequency allocation process creates a bandplan, which for technical reasons assigns white space between used radio bands or channels to avoid interference. In this case, while the frequencies are unused, they have been specifically assigned for a purpose, such as a guard band.
Most commonly however, these white spaces exist naturally between used channels, since assigning nearby transmissions to immediately adjacent channels will cause destructive interference to both. In addition to white space assigned for technical reasons, there is also unused radio spectrum which has either never been used, or is becoming free as a result of technical changes. In particular, the switchover to digital television frees up large areas between about 50 MHz and 700 MHz. This is because digital transmissions can be packed into adjacent channels, while analog ones cannot. This means that the band can be "compressed" into fewer channels, while still allowing for more transmissions. The television frequency band lies between 478MHz to 862MHz based on the ITU Radio Regulation. The Digital Video Broadcasting - Terrestrial (DVB-T) standard is used as a standard for TV broadcasting in Europe.
According to the Netherlands Radio and TV database, there are five DVB-T Multiplexer operators in Delft. These are listed in the table 1.

MUX Operator	Tx Location	Center Freq. (MHZ)	Channel No.	Bandwidth (MHz)	ERP (kW)
RTS Bouquet 1	Delft	722	52	8	1
NTS1 Bouquet 2	Delft	698	49	8	1
NTS2 Bouquet 3	Delft	762	57	8	1
NTS3 Bouquet 4	Delft	498	24	8	1
NTS4 Bouquet 5	Delft	522	27	8	1

Table 1: DVB-T MUX Operator

2 Cognitive Radio

To combat the overcrowding, new ways have been investigated to manage RF resources. The basic idea is to let people use licensed frequencies, provided they can guarantee interference perceived by the primary license holders will be minimal Dynamic spectrum access is a new spectrum sharing paradigm that allows secondary users to access the abundant spectrum holes or white spaces in the licensed spectrum bands. This promising technology is aimed to alleviate the spectrum scarcity problem and increase spectrum utilization.In the similar direction, cognitive radio works. It can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior

In this assignment dynamic spectrum sensing is used to detect the presence of DVB-T signal in different frequencies to find white spaces.

3 Our Objective

Our aim is to design, implement in GNURadio and test simple detector for digital television channels (DVB-T). Our task is to test detector under varying channel conditions and then show receiver operating characteristic of the detector. Eventually we need to improve the detection mechanism.In the process, the signal detector should sense the signals in a particular frequency within the TV broadcasting band, and must be able to decide if any signal is present or not based on certain threshold level.Finally, the detection performance of the receiver should also be evaluated.

4 Our Hypothesis

It should be noted that the signal detection characteristic of the receiver is closely related to the chosen threshold value. When the threshold value is high, the probability of false alarm will be low. However, this also reduces the probability of detection. The signals that fall below the threshold level will be considered absent. This will cause missed detection. When the threshold value is low, the probability of detection and the probability of false detection will be high. So, even the low level signals will be detected. However, noise that is above the threshold level will also be detected as a signal.Considering all the above mentioned scenarios we need to evalaute and improve the detection results.

5 Implementation

5.1 Energy Detection Method

Energy detection is a the signal detection mechanism based on Neyman-Pearson approach [5] [6]. The concept of energy detection mechanism is quite simple. The detector computes the energy of the received signal and compares it to certain threshold value to decide whether the desired signal is present or not. The energy of the signal is preserved in both time domain and frequency domain. The time domain representation of this mechanism is shown in Figure-1 The frequency domain representation of this mechanism is shown in Figure-2. Theoretically, whichever representation is used for signal detection and analysis, makes no difference in result. However in the former representation a pre-filter matched to the bandwidth of the signal is required.
In summary,in the energy detection mechanism, the received signal is first converted from time to frequency domain using FFT block.It is then amplified in the magnitude square block. Later, the computed average signal level is compared with the chosen threshold level to make a decision regarding the presence of primary users. If the received signal falls above the threshold, the frequency

is considered to be occupied.

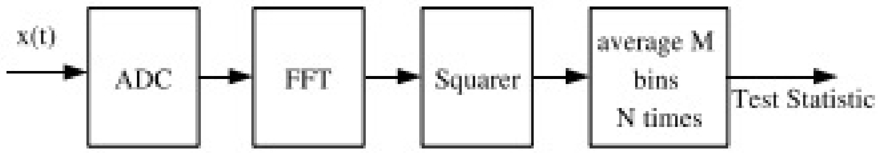


Figure 1: Frequency Domain :Energy Detection Mechanism

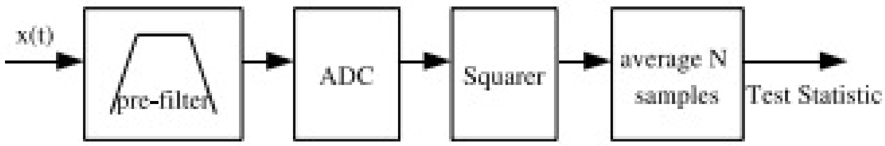


Figure 2: Time Domain :Energy Detection Mechanism

DVB-T dongles based on the Realtek RTL2832U(as a receiver) are used, since the chip allows transferring the raw I/Q samples to the host, which is officially used for DAB/DAB+/FM demodulation. It filters the received signal and performs an A/D conversion. The energy detector is implemented using the GNU SDR radio. GNU Radio[2] is a free software development toolkit that provides signal processing blocks to implement software-defined radios and signal processing systems. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. The A/D converted signal is then processed by the GNU radio software as shown in the energy detector block diagram in figure -3.

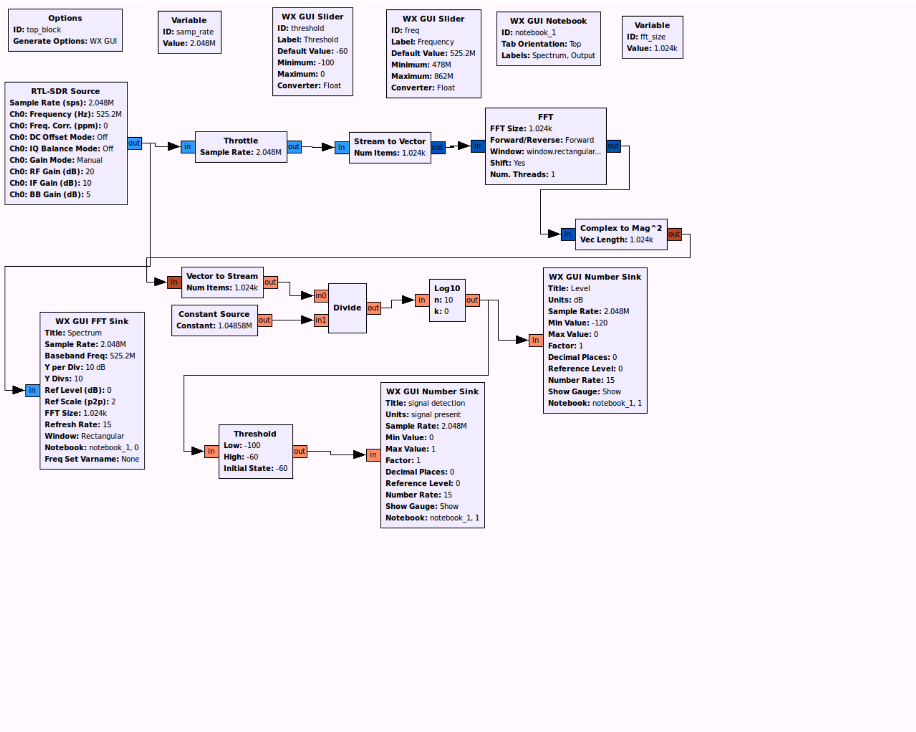


Figure 3: GNU radio: Block Diagram

6 Results and Analysis

The measurements are taken in two different places - EWI building and the TU Delft library. The threshold level is set to -60dB. A set of numerous readings needs to be taken in order to reach an optimal results. For the brevity of the report, a couple of results are shown in table -2

Frequency User	Central Frequency	TU Delft EWI Average Level (dB)	TU Delft Library Average Level dB	Average dB
RTS Bouquet 1	722	-51.65	-40.94	-46.29
NTS1 Bouquet 2	698	-49	8 -40.81	-46.25
NTS2 Bouquet 3	762	-63.67	-51.31	-57.49
NTS3 Bouquet 4	498	-57.98	-65.80	-61.89
NTS4 Bouquet 5	522	-52.23	–42.21	-47.22
Unknown-1	796.15	-38.45	-35.70	-37.07
Unknown-2	805.7	-55.85	-46.13	-50.99
Unknown-3	815.7	-48	-50.31	-51.15
Empty-1	8a62	-74.23	-63.21	-68.72
Empty-2	550	-69.82	-63.56	-66.69
Empty-3	630	-68.31	-69.92	-68.76
Empty-4	580	70.48	-65.25	-67.86

Table 2: Signal Measurements

Standard Deviation for Signals Present = 7.5 Mean signal = -49.037 Standard Deviation for no signals(empty) = 2.62 Mean signal = -67.0037

6.1 Signal Detection

GNU radio is used to detect the signal as shown in fig-4 using graphic interface of GNU radio.Readings are taken at frequency of 498MHz.

Figure 4: Signal Detection at 498 MHz

6.2 Missed Detection

This scenario happens in the case when there was a signal present and the SDR could not identify it(Figure-5 This was maybe due to poor strength of received signal as can be seen in the below mentioned figure as at 762 Mhz there lies a missed detection. Several environmental reasons can be held responsible for it.

Figure 5: Missed Detection at 762 Mhz

6.3 False Alarm

It was observed that despite of low signal strength we received detection for some frequencies. One of them was shown(403.2Mhz) in the below mentioned figure-6.

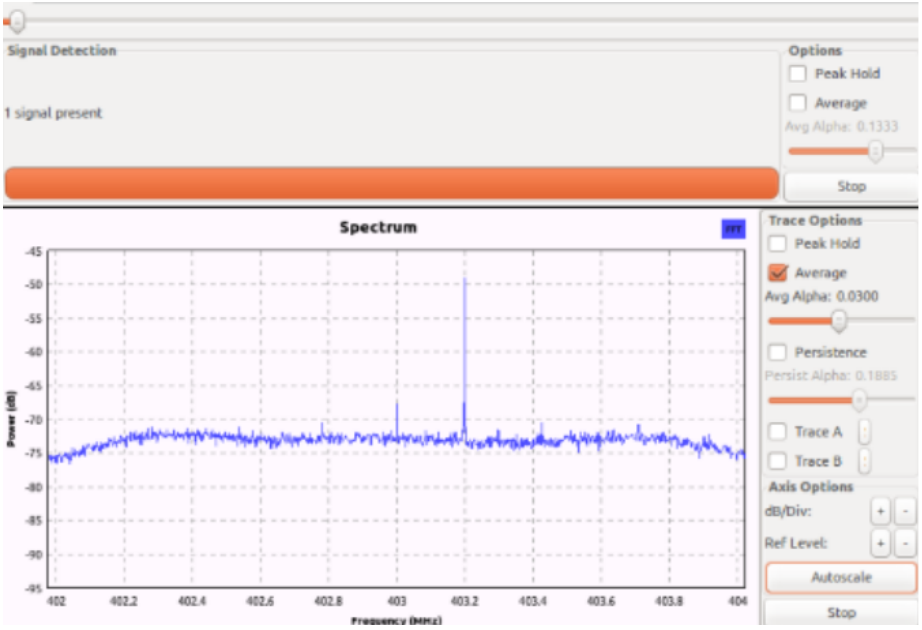
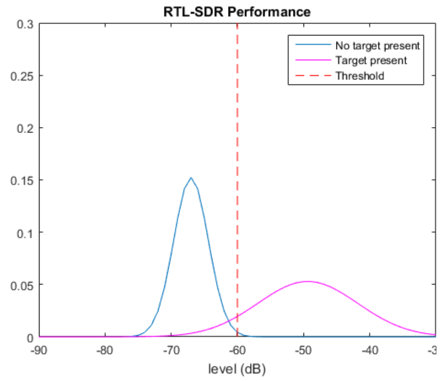
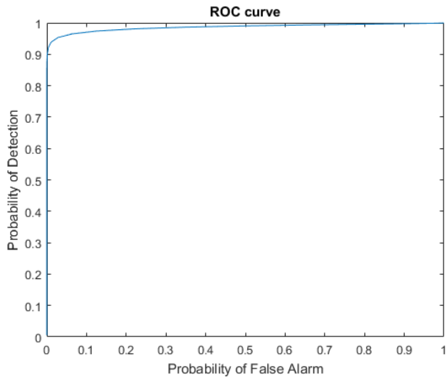


Figure 6: False Alarm



(a) Probabilities of detection and empty signal



(b) ROC plot

6.4 Performance of Energy Detector : Various Probabilities and ROC

Probabilities of detection and false alarm can be plotted using matlab code. Probability and ROC plots are shown in the figure-7a and figure-7b . This curve is plotted for threshold -60db from the readings shown in above table-2. The calculated probabilities for missed detection, false alarm and signal detection are depicted in table-3

Probabilities	Values
P_{fa}	0.0038
P_{d}	0.92
P_{md}	0.0762

Table 3: Probabilities for Missed Detection, False alarm and Detection

7 Conclusion

In a cognitive radio system, signal detection mechanism is required for spectrum sensing in order to identify occupied and vacant TV channels and hence to detect the availability of the vacant spectra. Energy Detection is one of the most sought after methods used in signal sensing.Cognitive radios have proposed as a possible solution to improve spectrum utilization via opportunistic spectrum sensing.

Spectrum sensing[4] is often considered as a simple detection problem. However the key challenge is the detection of the weak signal in real environment corrupted by noise and suffering from interference. Energy detector is one of the simplest detection mechanisms among those proposed so far. However despite considerable research work in cognitive radio detection mechanisms, experimental testing and verification of those mechanisms is yet in its infancy[3].

Using energy detection scheme, we could see that there indeed exists an optimal sensing time which achieves the a suitable tradeoff. Cooperative sensing can also be implemented based on the desired tradeoff levels to achieve reliable detections. The threshold play an important role as in it helps in deciding the accurate conditions for false alarms and missed detection.Probabilities of missed detection and false alarms serve as a barometer to check the performance of a cognitive radio and an ideal scenario would be where there is a higher probability for detection and lower probability for false alarms.

8 References

1. https://en.wikipedia.org/wiki/White_spaces_(radio)

2. https://en.wikipedia.org/wiki/GNU_Radio

3. C. Cordeiro, K. Birru and S. Shanker, "IEEE 802.22: The first worldwide wireless standard based on cognitive radios ," In proc. of DySPAN'05, November 2005

4. Energy Detector Prototype for Cognitive Radio System Sabita MAHARJAN , Kimtho PO , and Jun-ichi TAKADA Graduate School of Engineering, Tokyo Institute of Technology 2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8550 Japan E-mail: †sabita,kimtho,takada@ap.ide.titech.ac.jp

5. S. Kay, "Statistical decision theory I (Ch. 3)" and "Deterministic signals (Ch. 4)," in Fundamentals of Statistical Signal Processing, Detection Theory, pp.60-140, Prentice Hall, 1998.

6. H. Tang, "Some physical layer issues of wide-band cognitive radio systems," 2005 First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005), pp.151-159, Nov. 2005.

9 Matlab Script for Plot generation

```
Prob_empty = makedist('Normal', 'mu', -67.0037, 'sigma', 2.62);
Prob_sig_present = makedist('Normal', 'mu', -49.37, 'sigma', 7.53);
threshold = -60;
pfa = 1 - cdf(Prob_empty, threshold)
pd = 1 - cdf(Prob_sig_present, threshold)
level = [-90:-30];
figure(1);
plot(level, Prob_empty.pdf(level));
hold on
plot(level,Prob_sig_present.pdf(level), 'm');
title('RTL-SDR Performance')
hold on
Y = 0:0.1:0.3;
X = threshold * ones(size(Y))
plot(X, Y, 'r--');
legend('No target present', 'Target present', 'Threshold')
xlabel ('level (dB)');
pfa_ROC = 1 - cdf(Prob_empty, level);
```

```
pd_ROC = 1 - cdf(Prob_sig_present, level);
figure(2);
plot(pfa_ROC, pd_ROC);
title('ROC curve');
ylabel ('Probability of Detection');
xlabel ('Probability of False Alarm');
```