ET4394

Wireless Networking

GNU Radio Assignment Report

April 30, 2016

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Contents

1 Introduction

1.1 White Space

The white space refers to the frequencies allocated to broadcasting services (primary users), which are unused. Presence of white spaces in frequency bands reduces the utilization of the bands. In order to efficiently utilize the radio spectrum, secondary or unlicensed users are allowed to access these frequencies as along as the primary users are not using them.

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.

Table 1: DVB-T MUX Operator and Frequency in Delft

MUX Operator	Tx Location	Centre 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

1.2 Cognitive Radio

To efficiently utilize the radio spectrum, the secondary users need to find a white space frequency for transmission and move to another empty frequency when they detect the presence of primary user. This is called dynamic spectrum access. The secondary users use the cognitive radio property to perform dynamic spectrum access.

The cognitive radio is a radio that can be programmed and configured dynamically. One of the aspects of cognitive radio is spectrum sensing in which it senses the presence of signals in a particular frequency before transmission. When the frequency is unoccupied, it uses the frequency to transmit with defined parameters to avoid interference with other frequencies.

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

2 Project Description

2.1 Objective

The objective of this project is to implement a signal detector to find empty channels in broadcast television frequency band by detecting the presence of DVB-T signal. 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.

2.2 Hypothesis

The detection performance 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.

3 Implementation

3.1 Signal Detection Method

There are two types of methods for signal detection - signal demodulation and energy detection. The energy detection method is used in this project. The detector checks if a given frequency is occupied or not by comparing the received signal with the threshold. If the received signal falls above the threshold, then it concludes that a signal is present.

This method is independent of the type of the modulation used in signals. It only takes the signal level into account and compares with the threshold level to make a decision. However, there are certain disadvantages in this method. A noise that is above the threshold level will be detected as a signal (false alarm) and the signal that is below the threshold level will not be detected (missed detection).

3.2 Energy Detection in GNU Radio

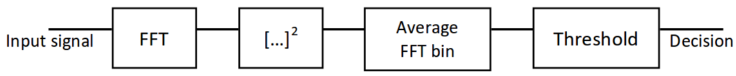


Figure 1: Energy detector

The energy detector implementation is as shown in figure 1. It needs a receiver to collect signal in particular frequency. This signal is first converted from time domain to frequency domain in the FFT block. It is then amplified in the magnitude square block. Later, the average signal level is computed and compared with the chosen threshold level to make a decision regarding the presence of primary users (actual signals). If the received signal falls above the threshold, the frequency is considered to be occupied.

The Realtek RTL-SDR 2838 dongle is used as a receiver in the project. This dongle is used to receive the DVB-T, DAB and FM signals. It has a frequency range of 24-1766MHz. It filters the received signal and performs an A/D conversion. The energy detector is implemented using the GNU radio, which is a software development toolkit that provides signal processing blocks to implement software defined radios and signal processing systems. The A/D converted signal is then processed by the GNU radio software as shown in the energy detector block diagram in figure 2.

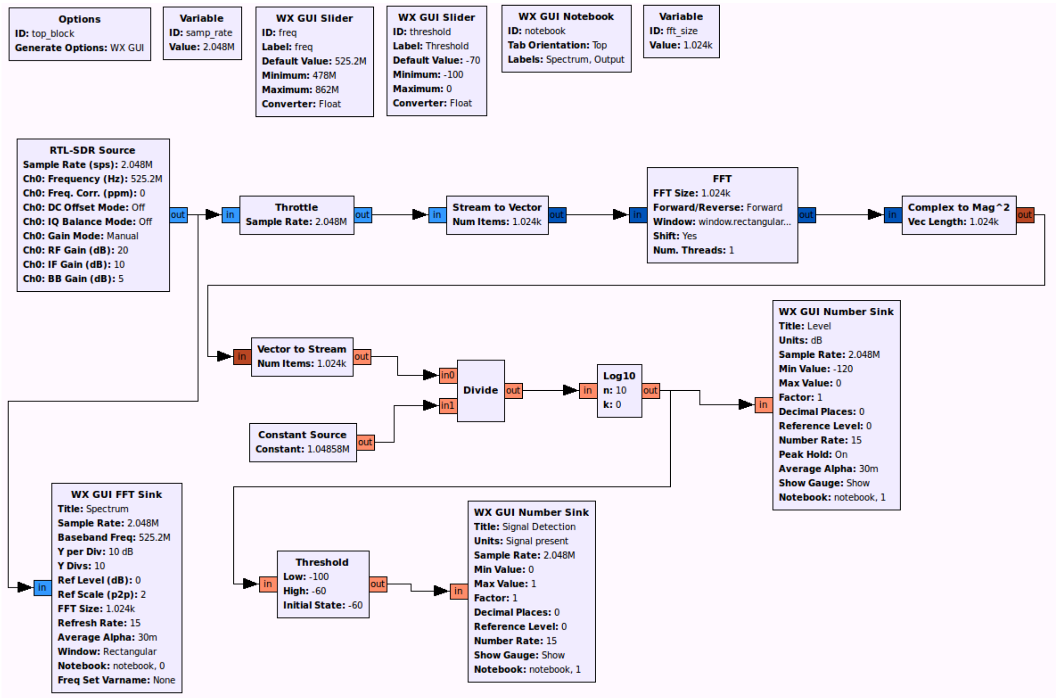


Figure 2: GNU radio block diagram for energy detection

4 Results and Analysis

The parameters such as signal profile, level and decision are measured. The measurements are taken in two different places - EWI building and the TU Delft library. The threshold level is set to -60dB. The results are shown in table 2. Measurements are taken for eight empty frequencies and eight frequencies in which signal exists. The average readings are computed for cases with and without signal presence. The average noise level is calculated using the measurements from empty frequencies. It is found to be -69.635dB.

4.1 Signal Detection

The spectrum of the DVB-T signal of RTS Bouquet 1, having a center frequency of 722MHz, is as shown in figure 3(a). The signal level received is indicated as -54dB. This is the instantaneous average level of the signal and it fluctuates continuously. To stabilize this fluctuation, the average

Table 2: Signal measurements with threshold = -60dB

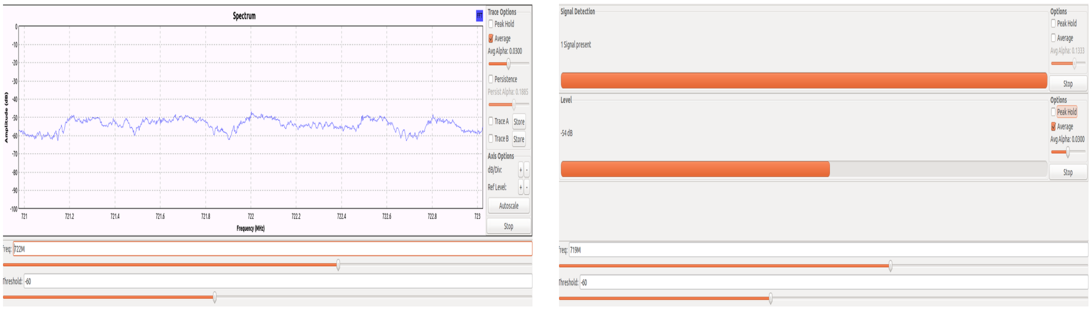
			TU Delft (EWI 1st floor)		TU Delft Library		Total Avg and Std. Deviation
Frequency User	Centre freq.(MHz)	Freq. Range(MHz)	Detection	Average Level(dB)	Detection	Average Level(dB)	
RTS Bouquet 1	722	718–726	✓	-51.5	✓	-47.94	Avg: -50.8325 Std. Dev: 5.40751
NTS1 Bouquet 2	698	694 –702	✓	-50.05	✓	-52.79	
NTS2 Bouquet 3	762	758 –766	✗	-61.40	✓	-50.31	
NTS3 Bouquet 4	498	494 –502	✓	-57.02	✓	-52.80	
NTS4 Bouquet 5	522	518 –526	✓	-55.41	✓	-55.21	
Unknown #1	795	791.7–800.6	✓	-32.71	✓	-45.70	
Unknown #2	806	801–810	✓	-50.99	✓	-46.13	
Unknown #3	818	812–819.5	✓	-49.06	✓	-54.31	
Empty #1	710	-	✗	-68.85	✗	-73.80	Avg: -69.635 Std. Dev: 2.72529
Empty #2	625	-	✗	-67.56	✗	-67.30	
Empty #3	510	-	✗	-60.82	✗	-69.14	
Empty #4	770	-	✗	-73.40	✗	-74.36	
Empty #5	862	-	✗	-68.75	✗	-74.24	
Empty #6	550	-	✗	-69.96	✗	-68.66	
Empty #7	630	-	✗	-69.73	✗	-70.22	
Empty #8	580	-	✗	-67.83	✗	-69.54	

option should be enabled. During the measurements, it has been set to 0.03 (as shown in figure 3(b)). Smaller alpha values give less fluctuations.

The received signal level -54dB is above the threshold level -60dB. Therefore, as shown in figure 3a(b), the presence of the signal is detected. The edges of the DVB-T signal in the RTS Bouquet 1 spectrum are shown in figures 4(a) and 4(b).

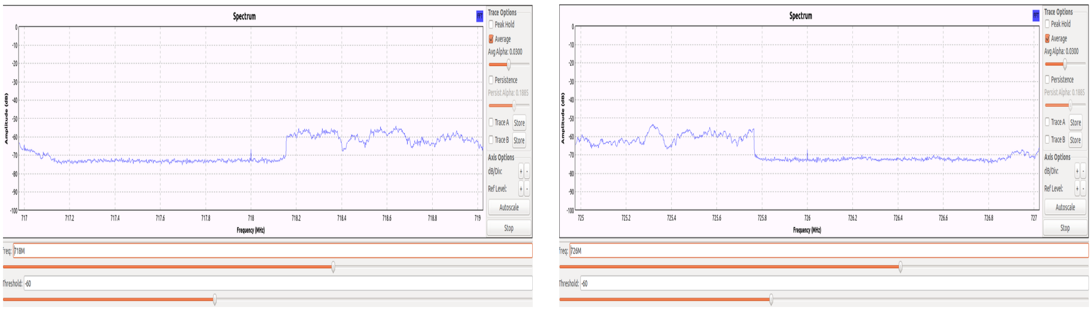
Some unknown signals are detected in the television broadcast band having frequency ranges of 791.7–800.6MHz, 801–810Mhz and 812–819.5Mhz. They have a high receive power and bandwidth of around -50dB and 10Mhz respectively. Based on the Netherlands Frequency Database, these are allocated for the purpose of Wideband Frequency Modulation(WFM) radio.

When there is no signal present in a particular frequency, the receiver detects only the noise levels and the detector declares that the frequency is empty if the noise level falls below the threshold value. If the noise level is above the threshold, false alarm occurs. This can be avoided by selecting an optimal threshold value which is slightly above this baseband signal and also very close to the average noise level. No signal presence is shown in figures 5(a) and 5(b).



(a) (b)

Figure 3: Signal detection at 722MHz



(a) (b)

Figure 4: Edge of the DVB-T signal in RTS Bouquet 1 spectrum

4.2 Missed Detection

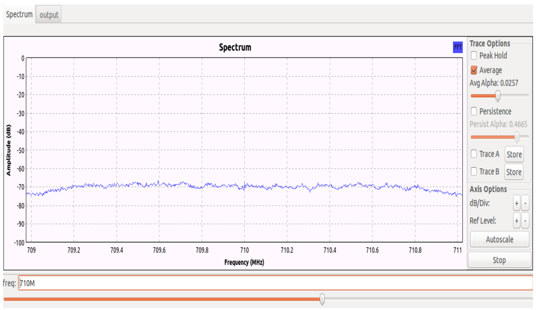
When the detector fails to detect the presence of a signal, missed detection occurs. It is usually due to low reception of the signal level. As explained earlier, this can be avoided to certain extent by decreasing the threshold levels. An example of a missed detection is shown in figures 6(a) and 6(b).

4.3 False Alarm

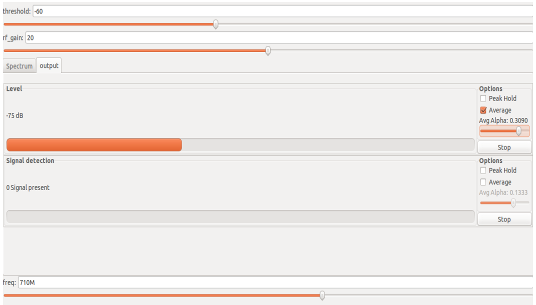
False alarm occurs when the system detects the presence of a signal in a particular frequency even when no signal is present. To mitigate this, the threshold value can be increased. Figure 7 shows the occurrence of false alarm at 489.6MHz.

4.4 Performance of the Energy Detector

The distribution plots for the presence and absence of signal, using a threshold of -60dB, is shown in figure 8(a). They are plotted using the average and standard deviation values obtained from the measurements in table 2.

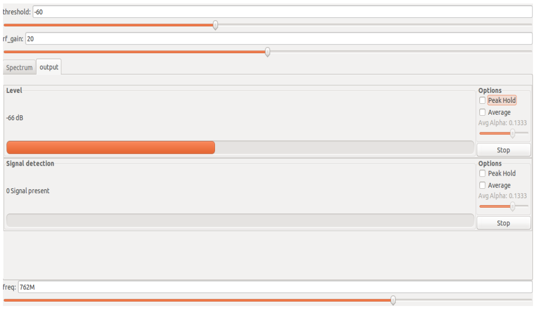


(a)

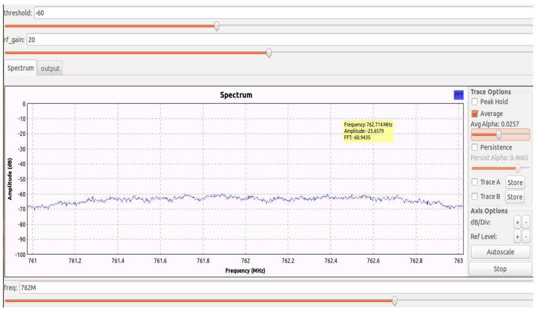


(b)

Figure 5: No signal presence at 710Mhz



(a)

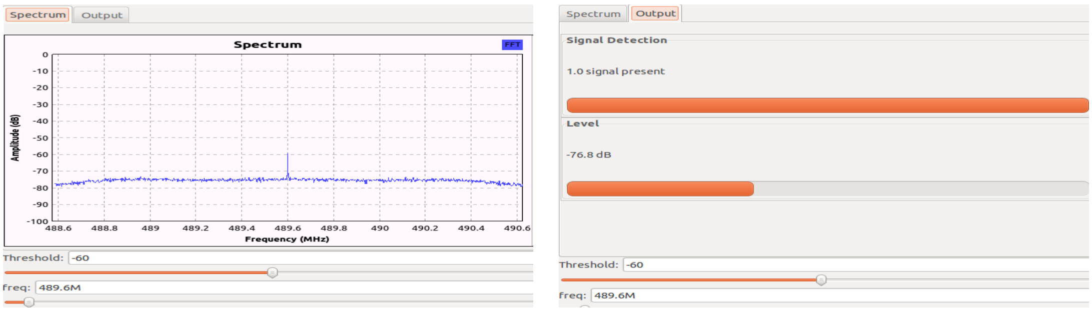


(b)

Figure 6: Missed detection at 762Mhz

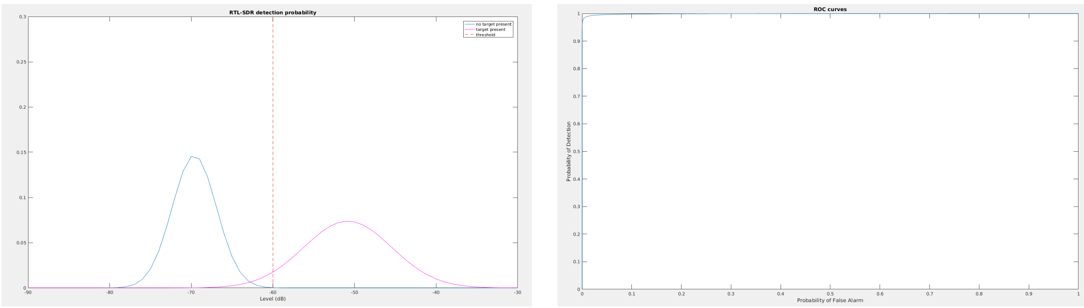
The probabilities of detection, missed detection and false alarm are calculated using MATLAB (script in Appendix). As shown in table 3, the probability of false alarm is almost 0% and the probability of detection is high with almost 95.53%. Hence the probability of missed detection has decreased to 4.47%. This shows that the selected threshold of -60dB is quite optimal.

The performance of the receiver depends on the probabilities of detection and false alarm. The Receiver Operating Characteristic (ROC) curve is plotted as shown in figure 8(b). The working area of the receiver will be under the ROC curve.



(a) (b)

Figure 7: False alarm at 489.6MHz



(a) Receiver performance for threshold of -60dB (b) ROC curve of the receiver

Figure 8

Table 3: Probabilities of detection, missed detection and false alarm

Threshold	-60dB
Pfa	0.00019973%
Pd	95.53%
Pmd	4.47%

5 Conclusion

Energy detection is one of the methods used for signal sensing. In order to obtain more accurate results cooperative sensing techniques have to be used in which the measurements need to be taken from different locations from multiple receivers. The measurements and detection results of each receiver have to be combined and analyze to obtain more accurate detection.

The selection of threshold value will be a trade off between probability of detection and probability of false alarm. Therefore, the threshold value should be carefully chosen such that the detector has higher detection probability and lower probability of false alarms.

6 References

1. http://www.radio-electronics.com/info/broadcast/digital-video-broadcasting/what-is-dvb-t-basics-tutorial.php

2. http://radio-tv-nederland.nl/dvbt/digitenne-kpntv.html

3. https://en.wikipedia.org/wiki/DVB-T

4. http://www.ijens.org/vol_13_i_05/131605-8787-ijet-ijens.pdf

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

7 Appendix

MATLAB script to plot the ROC curve of the receiver and to calculate the probabilities of detection, missed detection and false alarms.

```
Prob_noSig = makedist('Normal', 'mu', -69.63, 'sigma', 2.72);
Prob_Sig = makedist('Normal', 'mu', -50.83, 'sigma', 5.4);
threshold = -60;
pfa = 1 - cdf(Prob_noSig, threshold)
pd = 1 - cdf(Prob_Sig, threshold)
level = [-90:-30];

figure(1);
plot(level, Prob_noSig.pdf(level));
hold on
plot(level,Prob_Sig.pdf(level), 'm');
title('RTL-SDR detection probability')
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_noSig, level);
pd_ROC = 1 - cdf(Prob_Sig, level);

figure(2);
plot(pfa_ROC, pd_ROC);

title('ROC curve');
ylabel ('Probability of Detection');
xlabel ('Probability of False Alarm');
```