ET4394

GNU Radio Report

Wireless Networking

April 30, 2016

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Challenge the future

Contents

1 Introduction

The goal of this assignment is to implement a GNU radio and test a simple detector for digital television channels (DVB-T). DVB-T or Digital Video Broadcast - Terrestrial is the most widely used digital television standard in the world for terrestrial television transmissions with frequencies ranging from 470 to 862 MHz. Some salient features of the DVB-T network [1] include

- three modulation options - QPSK, 16QAM and 64 QAM
- four guard interval options - 1/32, 1/16, 1/8, and 1/4
- five forward error correction rates - 1/2, 2/3, 3/4, 5/6, and 7/8
- 6, 7, or 8 MHz channel bandwidths
- Video at 50 Hz or 60 Hz

DVB-T transmits compressed digital audio, digital video and other data using coded orthogonal frequency division multiplexing (COFDM or OFDM) [2]. Since this modulation uses a large number of sub-carriers, it delivers a robust signal even under severe channel conditions. DVB-T networks are widely used in Europe, America, Asia, Africa and Oceania.

The first section of the report describes the need for a cognitive radio. This is followed by a discussion on the working principles of the GNU radio, the measurements made, the results and the conclusion.

2 Cognitive Radio

Radio spectrum, which is vital for wireless communications, is a very limited resource. Different portions of the spectrum have been allocated exclusively to certain users, and a user allocated to a particular frequency cannot interfere with a user on another frequency. This fixed spectrum access(FSA) policy is not an effective solution because, reserving a small portion of the spectrum is very expensive and furthermore, there is no guarantee that the bandwidth will be utilized to its full extent. Suppose, there are two licensed users, A and B, to two different portions of the spectrum. If the frequency that B is assigned to is empty, A cannot use it for its own transmission purposes because it is not a licensed user of that frequency. Most of the spectrum has been allocated statically and thus, there is an acute scarcity of free spaces in the spectrum.

One of the ways to overcome the aforementioned problem is the use of a dynamic spectrum access (DSA) policy. In this method, a set of users, the "primary users", are allocated a part of the spectrum. This does not imply an exclusive access to these users. However, primary users are given higher priority. Other users, called the secondary users, can use this part of the spectrum temporarily, as long as no primary user is actively using it. When a primary user tries to utilize the spectrum, the secondary user must relinquish use or share the spectrum with the primary user, as long as the primary user's operation is not disrupted. This provides a flexible use of the spectrum and results in better utilization. A cognitive radio has the capability to sense the radio environment for a particular frequency and to judge whether this frequency can be used for transmission [3]. The radio actively listens to the frequency and when the channel is free, it facilitates transmission without causing interference.

Spectrum sensing of the DVB-T network shows that many portions of the spectrum remain empty. These unused regions are called "white spaces". This task involves spectrum sensing of the DVB-T channels because, they are used mainly for television transmission purposes and are not as crowded as the radio spectrum. By identifying the white spaces and permitting secondary users to use them, spectrum utilization can be improved manifold. The DVB-T MUX operator and frequencies used in Delft, and belonging to the regional broadcast area of RTV West, are shown in Table 1. Out of these five channels, the first one (RTS Bouquet 1) follows a free-to-air broadcast, i.e., broadcast over a wireless network without encryption.

MUX Operator	Center Freq. (MHz)	Channel No.	BW (MHz)	Effective Radiated Power, ERP(kW)
RTS Bouquet 1	722	52	8	1
NTS1 Bouquet 2	698	49	8	1
NTS2 Bouquet 3	762	57	8	1
NTS3 Bouquet 4	498	24	8	1
NTS4 Bouquet 5	522	27	8	1

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

3 Objective

Spectrum sensing can be performed in three ways [3] -

- Transmitter detection - detection is based on the signal from the primary transmitter
- Cooperative detection - secondary users share their sensing information to arrive at a combined decision for an accurate detection
- Interference-based detection - detection using an interference temperature model

The aim of this task is to build an energy detector (simplest method in the transmitter detection category) using GNU radio that will be used to identify the busy channels and the white spaces in the DVB-T spectrum. For this purpose, a threshold is defined. Based on this threshold, the detector must decide whether a signal is present or not at a particular frequency. The final objective is three-fold - test the detector under varying channel conditions, show the receiver operating characteristics of the detector and improvize on the detection mechanism.

4 Implementation Strategy

Spectrum sensing is performed through an energy-detection mechanism. The block diagram of the energy detector is shown in Figure 1. The input signal obtained from the receiver is subject to a band pass filter so as to remove any disturbances occurring outside the frequency of interest. The signal strength is extracted, by subjecting the signal to the squaring block and then, it is compared against a specified threshold. If the signal strength is greater than the threshold, then it indicates that the signal is present (H_1). If the strength is lower than the threshold, it implies that the signal is absent (H_0).

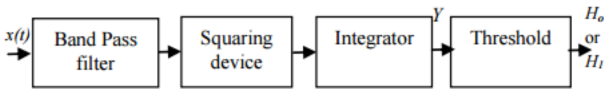


Figure 1: Block diagram of Signal Detector [3]

5 Operation

The hardware used in the detection mechanism is shown in Figure 2. It consists of an RTL2832U SDR dongle, two detachable DVB-T antennae, and a cable to connect the antenna to the dongle. The RTL2832U SDR dongle along with the R820T tuner functions as the receiver and can be used to tune into signals from 24 MHz to 1850 MHz. A wide range of FM signals, AM signals, CW (morse code), unencrypted radio signals, pager signals, etc., can be picked up by this configuration [4].

The antenna picks up DVB-T signals of a set frequency and the receiver passes on the signals for further processing, as per the block diagram shown in Figure 1. GNU radio is a free, open-source software development kit that provides signal processing blocks to implement software-defined radios such as cognitive radio and signal processing systems [5]. The energy detector is implemented using GNU radio software

Figure 2: Hardware setup for Signal Detector

and the block setup is shown in Figure 3.

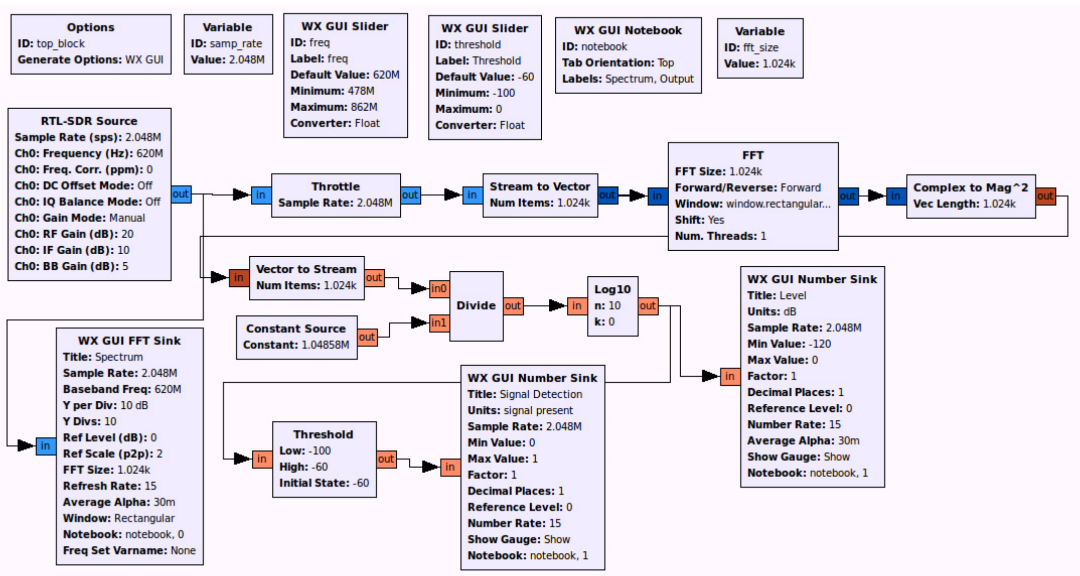


Figure 3: Signal detector implementation in GNU Radio

From Figure 3, it can be seen that there are 6 blocks on the top without any connections - Options, Variable, WX GUI Slider, WX GUI Notebook, and Variable. These are similar to global variables that are accessible throughout the environment. The threshold for detection is set to -60 dB. The range of frequency detection is between a minimum frequency of 478 MHz and a maximum frequency of 862 MHz, corresponding to the DVB-T range. Table 2 lists the parameters used in the GNU radio.

Block	Value
RTL-SDR Source	Sample Rate: 2.048 M samples/s, Channel Frequency: 620 MHz, RF Gain: 20 dB, IF Gain: 10 dB, BB Gain: 5 dB
Throttle	Sample Rate: 2.048 M samples/s
Stream to Vector	Number of items: 1.024 k
FFT	FFT Size: 1.024 k, Number of Threads: 1
Complex to Mag^2	Vector Length: 1.024 k
Vector to Stream	Number of items: 1.024 k
Constant Source	Constant: 1.04858 M
Log10	n: 10, k: 0
WX GUI Number Sink	Title: Level, Units: dB, Sample Rate: 2.048 M, Min Value: -120, Max Value: 0, Factor: 1, Decimal Places: 1, Number Rate: 15, Average alpha: 30m
Threshold	Low: -100, High: -60, Initial State: -60
WX GUI Number Sink	Title: Signal Detection, Units: signal present, Sample Rate: 2.048 M, Min Value: 0, Max Value: 1, Factor: 1, Decimal Places: 1, Number Rate: 15
WX GUI FFT Sink	Title: Spectrum, Sample Rate: 2.048 M, Baseband Freq: 620 M, Y per div: 10 dB, Y Divs: 10, Ref scale(p2p): 2, FFT Size: 1.024 k, Refresh Rate: 15, Average Alpha: 30m

Table 2: Parameters of GNU Radio blocks

6 Measurement and Analysis

The individual parts of the hardware are assembled, and the dongle is plugged into the USB port. Once the blocks are drawn, the flowgraph is compiled and executed. The frequency to be changed can be specified under the WX GUI Slider (Default value), RTL-SDR Source (Ch0 frequency) and WX GUI FFT Sink (Baseband frequency) blocks. The measurements recorded at two different locations are tabulated in Tables 3, 4, 5, and 6 . Signals of 12 different frequencies and white spaces of 13 different frequencies are measured. Every time the frequency is changed, the flow graph must be compiled and executed to view the signal detector output on the top block. The level must be allowed to stabilize for sometime before being noted. There are four different case scenarios

- when a signal is present and is detected correctly (signal detection)
- when a signal is present and is missed (missed detection)
- when a signal is not present and is identified correctly (correct rejection)
- and when a signal is not present and is incorrectly identified that a signal is present (false alarm)

Out of these four, signal detection and correct rejection are good. Missed detection and false alarm negatively impact the detection performance.

Signal Detection:
On the output tab of the top block, whenever a signal is detected, an output of "1 signal present" is displayed. The power level of the signal is also displayed. When the average option under "Level" is not checked, this value keeps changing wildly due to signal variations. In order to attain a more stable output, the average option is enabled and the average alpha value is set to 0.03. By setting the average value, the average of past measurements is considered. On the spectrum tab, disabling the average button on "Trace options" will give rise to an erratic signal, as shown in Figure 4a, for the center frequency 522 MHz. When it is enabled, the average value of the signal is taken, which smoothens the signal to a certain extent, as it is shown in Figure 4b for the same frequency. The GUI window extends only for a bandwidth of 2 MHz around the specified center frequency. As mentioned in the introduction of the assignment, the channel bandwidth may be 6, 7 or 8 MHz. For the channel frequency 522 MHz, the signal

S.No	User	Center Frequency (MHz)	Signal Detected	Average Level (dB)	Overall Average (dB)
1	RTS Bouquet 1	722	Yes	-58.5	-59.79
2	NTS1 Bouquet 2	698	Yes	-56.2	
3	NTS2 Bouquet 3	762	Yes	-55.8	
4	NTS3 Bouquet 4	498	Yes	-45.9	
5	NTS4 Bouquet 5	522	Yes	-50.9	
6	Random 1	700	Yes	-51.6	
7	Random 2	800	Yes	-50.8	
8	Random 3	526.4	Yes	-68.8	
9	Random 4	600	Yes	-78.0	
10	Random 5	500	Yes	-45.6	
11	Random 6	505	Yes	-77.2	
12	Random 7	490	Yes	-78.2	

Table 3: Detection of signal at Roland Holstlaan, 13th floor, Delft (Coordinates: 51.996069, 4.354131)

S.No	User	Center Frequency (MHz)	Signal Detected	Average Level (dB)	Overall Average (dB)
1	Empty	530	No	-79.0	-77.63
2	Empty	540	No	-77.7	
3	Empty	650	No	-77.2	
4	Empty	670	No	-78.6	
5	Empty	730	No	-77.3	
6	Empty	770	No	-77.0	
7	Empty	750	No	-77.8	
8	Empty	550	No	-76.3	
9	Empty	560	No	-77.8	
10	Empty	610	No	-76.9	
11	Empty	630	No	-77.5	
12	Empty	635.4	No	-78.4	
13	Empty	489.6	No	-78.2	

Table 4: Detection of empty spaces at Roland Holstlaan, 13th floor, Delft (Coordinates: 51.996069, 4.354131)

is seen to cross the threshold of -60 dB around 518.2 MHz in Figure 5a. After that, the level falls below the threshold at around 525.8 MHz, as seen in Figure 5b. This gives the channel a bandwidth of 7.6 MHz.

Missed Detection:
While certain signals are detected at one location, they might be missed out at another location. From Tables 3 and 5, it can be seen that signals Random 3, 4, 6 and 7 are detected at Roland Holstlaan whereas, not picked up at EWI. This is called a missed detection and is attributed to poor signal reception.

Correct Rejection:
When the power level goes below -60 dB, the signal detector decides that there is no signal present and this is repesented by a '0'. The output of the top block for this case is shown in Figure 7.

False Alarm:
False alarm corresponds to a scenario where noise is interpreted as a signal present. There is no useful signal present at the particular frequency, but the signal detector indicates that there is a signal present. Figure 8 corresponds to a false alarm scenario. One way to minimize the probability of false alarm is to increase the threshold. But, this comes with an added risk that weaker signals might be missed out.

S.No	User	Center Frequency (MHz)	Signal Detected	Average Level (dB)	Overall Average (dB)
1	RTS Bouquet 1	722	Yes	-59.2	-62.0
2	NTS1 Bouquet 2	698	Yes	-53.9	
3	NTS2 Bouquet 3	762	Yes	-57.3	
4	NTS3 Bouquet 4	498	Yes	-56.2	
5	NTS4 Bouquet 5	522	Yes	-55.9	
6	Random 1	700	Yes	-52.1	
7	Random 2	800	Yes	-47.1	
8	Random 3	526.4	No	-72.6	
9	Random 4	600	No	-78.4	
10	Random 5	500	Yes	-54.4	
11	Random 6	505	No	-78.3	
12	Random 7	490	No	-78.6	

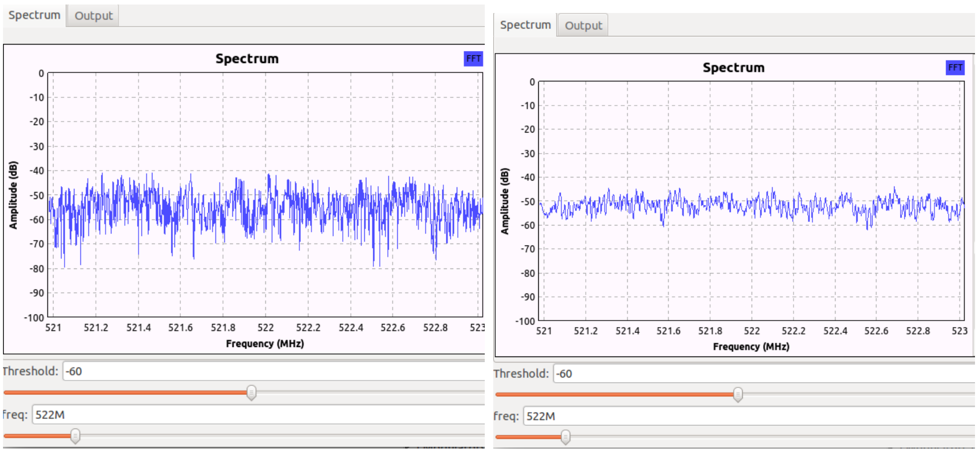
Table 5: Detection of signal at EWI (3rd floor) (Coordinates: 51.998515, 4.374171)

S.No	User	Center Frequency (MHz)	Signal Detected	Average Level (dB)	Overall Average (dB)
1	Empty	530	No	-78.2	-77.99
2	Empty	540	No	-78.4	
3	Empty	650	Yes	-78.0	
4	Empty	670	No	-76.9	
5	Empty	730	No	-77.5	
6	Empty	770	No	-78.8	
7	Empty	750	No	-78.9	
8	Empty	550	No	-78.4	
9	Empty	560	Yes	-77.1	
10	Empty	610	No	-76.4	
11	Empty	630	No	-78.1	
12	Empty	635.4	No	-79.2	
13	Empty	489.6	No	-76.4	

Table 6: Detection of white spaces at EWI (3rd floor) (Coordinates: 51.998515, 4.374171)

7 Receiver Operating Characteristics

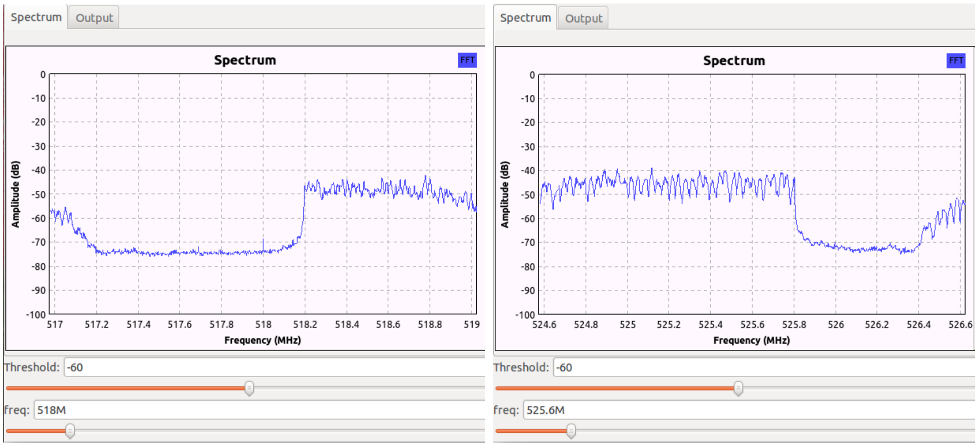
A MATLAB script was used to plot the detection probabilities for the threshold of -60 dB and this is shown in Figure 9a. The detection probability, P_d, is equal to 46.97 %, and the probability of false alarm, P_f is equal to 0. Despite this, the probability of missed detection, P_m, is equal to 1-P_d = 53.03 %, which is quite high. This might result in a greater chance of interfering with another transmission. By reducing the threshold, P_d can be increased. Figure 9c shows that by reducing the threshold to -75 dB from -60 dB (exactly where the two curves intersect), P_d increases to 88.4 % and thus, P_m is equal to 11.6 %. P_f in this case becomes equal to 0.02687 %. If the threshold is reduced any further, say to -80 dB, P_d becomes 94.73 %, whereas, P_f also increases to 99.63 %. This indicates that the detector will be very sensitive to noise and easily misinterpret noise as a valid signal. The receiver operating characteristic curve is shown in Figure 9b. The curves are not very smooth. This can be attributed to the discrepancies in the readings depending on the location, the hardware, and the interference due to noise. The curve must be as close to 1 as possible, so that it can maximize the area under the curve, which in turn signifies a higher accuracy in operation.



(a) Spectrum output with average option disabled

(b) Spectrum output with average option enabled

Figure 4: Spectrum output of frequency 522 MHz



(a) Spectrum output at 518.2 MHz

(b) Spectrum output at 525.8 MHz

Figure 5: Spectrum output of 522 MHz channel

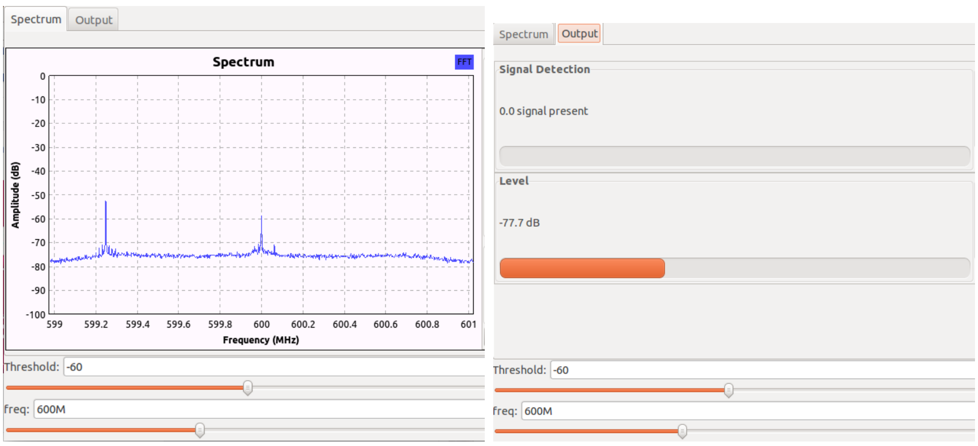


Figure 6: Missed detection at 600 MHz

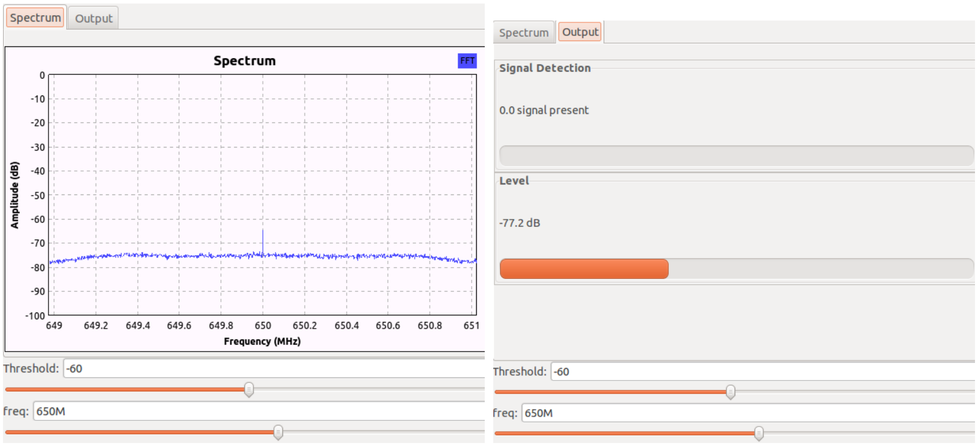


Figure 7: No signal present at 650 MHz

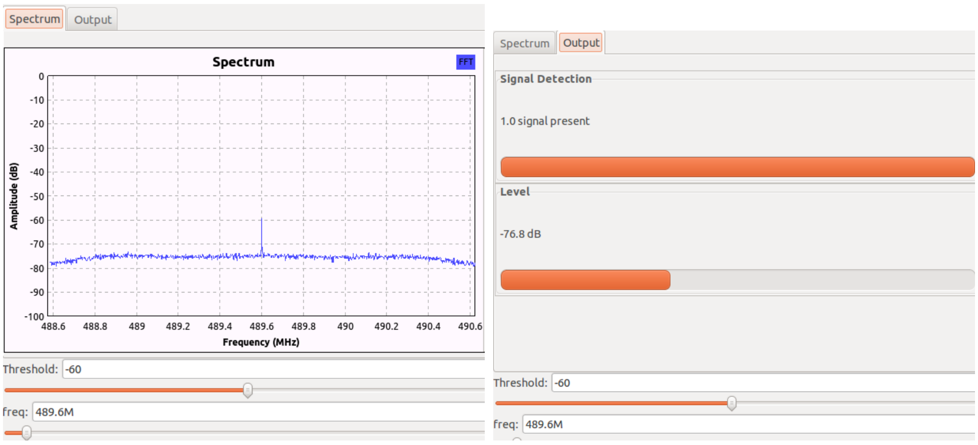
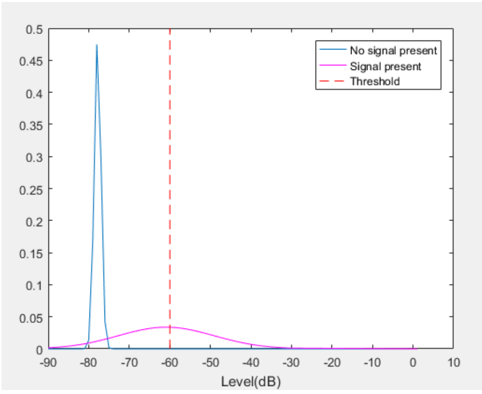
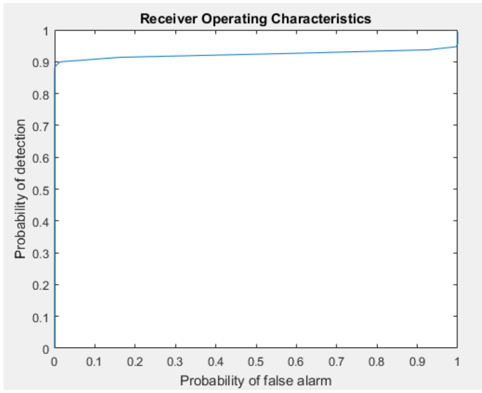


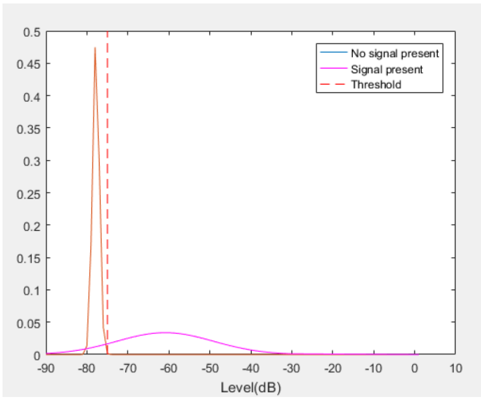
Figure 8: False Alarm at 489.6 MHz



(a) Receiver performance curve for threshold of -60 dB



(b) Receiver Operating Characteristics



(c) Receiver performance curve for threshold of -75 dB

Figure 9: Receiver performance evaluation

8 Conclusion

The characteristics of a cognitive radio using the energy detection technique has been analyzed. There are numerous factors affecting the energy detection mechanism such as the location of the receiver, varying channel conditions, threshold, etc. Threshold selection is vital because, it must be low enough to detect weak signals and thereby, improve the probability of detection, but not so low that it mistakes a noise for a signal, i.e., does not increase the probability of false alarm. Two of the most obvious advantages of the energy detection method that were evident are that, this method is simple in its implementation and has a short sensing time. With varying channel conditions, shadowing, fading and other effects, spectrum sensing can be difficult. To improve the detection mechanism, a co-operative sensing scheme is used, where the sensing results are collected from all users in order to collectively decide whether a signal is present or not. This method fine tunes the sensing process.

9 References

1. http://www.radio-electronics.com/info/broadcast/digital-video-broadcasting/what-is-dvb-t-basics -tutorial.php
2. https://en.wikipedia.org/wiki/DVB-T
3. http://www.ijens.org/vol_13_i_05/131605-8787-ijet-ijens.pdf
4. https://www.adafruit.com/products/1497
5. https://en.wikipedia.org/wiki/GNU_Radio

Appendix

```
%I = importdata('file.txt'); % Import file with Average Level values
%                            % File contains two columns of the form:
%                            % Average Level(Signal Present) Average Level(Signal Absent)
%S = std(I,0,1);             % Compute Standard Deviation
%M = mean(I,1);              % Compute Mean

M(1) = -60.89583; M(2) = -77.80833;
S(1) = 11.8; S(2) = 0.8177;
% Create a normal probability distribution with mu = final average and
% sigma = standard deviation
Psignalpresent  = makedist('Normal','mu',M(1),'sigma',S(1));
Psignalabsent   = makedist('Normal','mu',M(2),'sigma',S(2));
threshold   = -75;
% Compute cumulative distributed function values for the probability
% distribution values at the threshold level
Pdetection  = 1-cdf(Psignalpresent,threshold)
Pfalsealarm = 1-cdf(Psignalabsent,threshold)

Level = [-90:-30];
% Receiver Performance
figure(1);
plot(Level,Psignalabsent.pdf(Level));
hold on
plot(Level,Psignalpresent.pdf(Level),'m');
hold on
X = threshold*ones(size(Y)); Y = 0:0.1:0.5;
plot(X,Y,'r--');
xlabel('Level(dB)');
legend('No signal present','Signal present','Threshold');

% ROC Plot
Pfa_ROC = 1-cdf(Psignalabsent,Level);
Pd_ROC = 1-cdf(Psignalpresent,Level);
figure(2);
plot(Pfa_ROC, Pd_ROC);
title('Receiver Operating Characteristics');
xlabel('Probability of false alarm');
ylabel('Probability of detection');
```