GNU Radio Project Report

ET4394 Wireless Networking

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Challenge the future

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Introduction

1.1. DVB-T White Space

In some services, there are some unused or empty frequency bands that are potential to be utilized by a secondary user. For example in television broadcasting band, it might not be all the channels are occupied by TV operator in certain area. The rest of frequencies in that band are empty and unused. The empty spectrum in either frequency or time domain is called white space frequency. The more white space frequencies exist in particular band, the less efficient the utilization of that band. Therefore, by enabling the secondary user or unlicensed user to use the spectrum band together with the primary user, the spectrum utilization will be optimized.

Based on ITU Radio Regulation, television frequency band lies from 478 MHz to 862 MHz. In Europe, Digital Video Broadcasting – Terrestrial (DVB-T) standard is used as a standard for TV broadcasting. In DVB-T standard, a carrier signal can multiplex several television and audio broadcasts by using Orthogonal Frequency Division Multiplex (OFDM) that enables several modulation systems such as QPSK, 16QAM and 64QAM. The bandwidth for DVB-T carrier can be 6 MHz, 7 MHz or 8 MHz [1].

Based on Nederland Radio and TV database, there are five DVB-T Multiplexer operators that are currently operating in Delft area. Table 1 explains the list of multiplexer (MUX) operator in Delft area as well as the frequencies (channels) that are used by each operator.

Table 1. DVB-T MUX Operator & Frequency in Delft [2]

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

Some cities around Delft such as Den Haag, Rotterdam, and Zoetermeer are using the same DVB-T channels (frequencies) as in Delft. However their transmitters are located in each city and are transmitting with higher ERP.

1.2. Cognitive Radio

In order to utilize the white space frequency without interfering the primary user, a secondary user has to find an empty frequency transmit and move to another frequency whenever it detects the presence of primary user. The ability of a system to make use this empty space as communication resources is called dynamic spectrum access. In order to be able to perform dynamic spectrum access, the secondary user should apply cognitive radio property. Cognitive radio system has abilities to sense the presence of signal in a certain frequency and to seek the opportunity to use a particular frequency. It dynamically listens to the particular frequency first before start transmitting. Once the frequency is free, it will use that particular frequency and transmit with defined parameter to avoid interference with other frequency.

One of the aspects of cognitive radio is spectrum sensing. Spectrum sensing techniques are used for detecting whether a channel is empty or being used by another user. By using spectrum sensing, the system will be able to determine the available spectrum to use and be able to detect the presence of primary spectrum users. In order to be able to detect the presence of DVB-T signal in particular frequency, the spectrum sensing has to be applied. In this project, sensing and detection of DVB-T signal method will be implemented in order to decide whether there is a signal presence in a certain frequency.

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Project Description

2.1. Objective

The objective of this project is to create a signal detector that is able to detect the presence of the DVB-T signal in order to search the empty channel available in broadcast television frequency band. The detector should be able to perform signal sensing in particular frequency within TV broadcasting band and be able to decide whether there is a signal or not, based on certain level threshold. In this project, the detection performance of the receiver will also be evaluated.

2.1. Hypothesis

The detection performance of a receiver is associated with its threshold value. The higher threshold value applied, the lower the probability of false alarm. Consequently, it also reduces the probability of detection. A signal presence that has level below the threshold will be considered as an absence. Therefore, it leads to the missed detection of a signal. On the other hand, the lower threshold value applied, the higher the probability of false alarm and the higher the probability of detection. Hence, the signal that has low level will be detected. However, a noise that has level slightly above the threshold will also be considered as a signal presence. Therefore it will give the false detection.

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Implementation

3.1. Approach

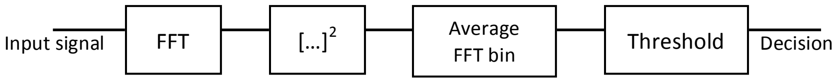
In order to detect the presence of a signal, there are two detection approaches that can be used. The first one is signal demodulation and the other one is energy detection. There are advantages and disadvantages in both approaches.

In the first approach, the demodulator is used to demodulate the digital signal into video channel. In DVB-T system, a carrier frequency (8 MHz bandwidth) can contains up to 12 channels depending on the channel quality and its modulation. By demodulating the signal, we will be able to see the broadcast channel contained in particular frequency and detect the signal in that particular frequency. However, when there is an analog TV signal or signal with other modulation types exist in broadcasting band, the demodulator will not be able to demodulate such signal. The detector will deduce that there is no signal presence in that particular frequency. Therefore, it will result in the miss detection of signal.

In this project, the energy detection approach is used. The detector decides whether there is a signal or not by detecting the received level of signal and compare it with the threshold. If the received level is above the threshold, then it deduces a signal presence. This approach is simpler than the demodulation method. Moreover, it is independent of the modulation type of a signal. It can detect signals with any kind modulation as long as its level is above the threshold. However, a noise that is above the threshold may be detected as a real signal and a signal that is below the threshold may not be detected. In this case, false alarm and miss detection is likely to be occurred.

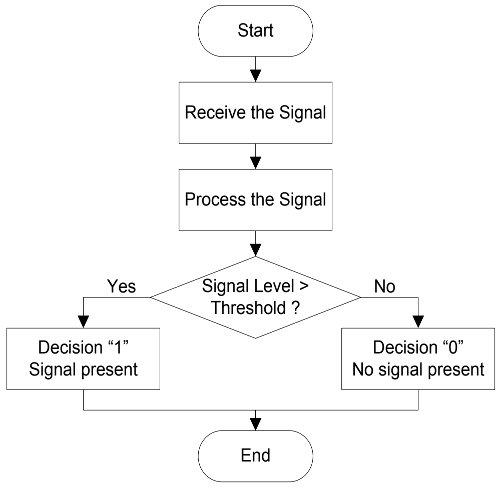
3.2. Implementation in GNU Radio

In order to implement the energy detection method, a receiver is needed for collecting the signal in particular frequency. After that, the signal is processed into FFT block in order to transform the signal from time domain into frequency domain. In order to amplify the signal magnitude, magnitude square block is used. By applying certain threshold level, the signal level then compared to the threshold in order to create a decision. Picture 2 describes the energy detection process in frequency domain.



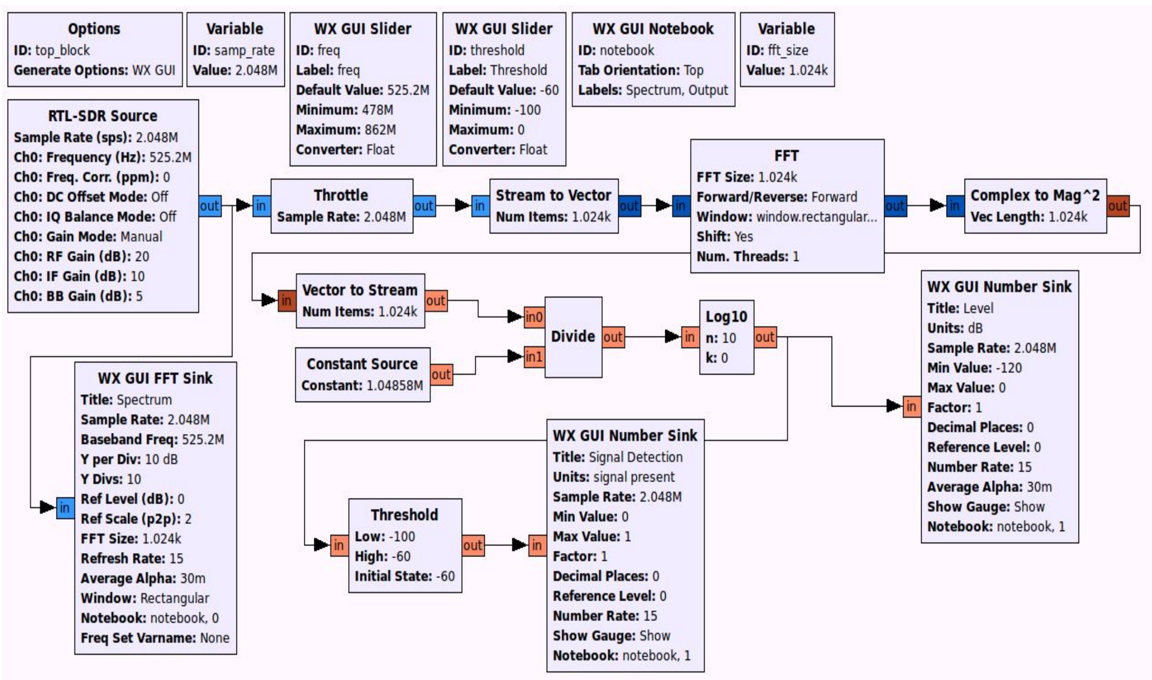
Picture 2. Energy Detector Implementation in Frequency Domain

Flowchart in Picture 3 describes how the detection process works.



Picture 3. Signal Detection Process Flowchart

In this project, Realtek RTL-SDR 2838 dongle is used as a receiver system. Basically, RTL-SDR 2838 dongle is used for receiving the DVB-T, DAB and FM signal. However, this dongle can also work as a wideband receiver. Its tuner type is Rafael Micro R820T that has frequency range of 24 – 1766 MHz. The dongle filters the received signal and performs A/D signal conversion. After that, the output of the RTL-SDR dongle is processed through block diagram in GNU radio software. GNU radio is an open source software development toolkit that provides the signal processing runtime and processing blocks [3]. Picture 4 depicts the energy detector block diagram that is implemented in GNU radio software.



Picture 4. GNU Radio Diagram Block of Energy Detection

Table 2 explains the function of and the parameter applied in GNU radio block:

Table 2. GNU Radio Diagram Block Description

Block Name	Description	Parameter
RTL-SDR Source	Getting the input of signal from RTL2838 dongle	Sample Rate : 2.048 M Samples/s RF Gain : 20 dB, IF Gain : 10 dB, Baseband Gain : 5 dB, BW : 1 MHz
Throttle	Limiting the sample per sec (sampling rate)	Sample Rate : 2.048 M Samples/s
Stream to Vector	Converting stream data into vector in order to be processed in FFT	Num Items : fft_size (1024)
FFT	Fast Fourier Transform process	FFT Size : 1024 Window : Rectangular
Complex to Mag^2	Calculating magnitude squared value of FFT sample output	Vector Length : fft_size (1024)
Vector to Stream	Converting Vector to Stream after FFT process. (The opposite of Stream to Vector block)	Num Items : fft_size (1024)
Constant Source	Generating (FFT size)^2 value as a divisor	(fft_size)^2
Divide	Getting the average bins of FFT Result (Complex to Mag^2) by (FFT size)^2 in order to get the power	
Log10	Converting the power level into dB $P_{(dB)} = 10*\log^{10}(P_{Watt})$	
WX GUI FFT Sink (Spectrum)	Displaying FFT results of spectrum	Sample Rate : 2.048 M Samples/s Baseband freq : freq FFT Size : fft_size (1024) Window : Rectangular
WX GUI Number Sink (Level)	Displaying the level value in dB	Sample Rate : 2.048 M Samples/s Min value : -120, Max value : 0, Average Alpha : 0.03
Threshold	Setting the threshold with upper limit -60 dB	threshold
WX GUI Number Sink (Signal Detection)	Displaying the signal detection based on threshold set. "1" if there is a signal present and "0" if there is no signal present	Sample Rate : 2.048 M Samples/s Min value : 0, Max value : 1
Variable Sampling Rate	Define the sampling rate	samp_rate : 2.048 M Sample/s
Variable FFT Size	Define the FFT Size	fft_size : 1024
WX GUI Slider Frequency	Define the frequency	freq, freq. min : 478 MHz, freq. max : 862 MHz
WX GUI Slider Threshold	Define the threshold. It will give "1" if the signal level is above -60 dB and will give "0" if the signal level is below -60 dB.	threshold, default = -60 dB, min : -100 dB, max : 0 dB

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Results & Analysis

The parameters captured during the measurement are signal (spectrum) profile, level and decision. The measurements are performed in 2 different locations: Rontgenweg Delft & EWI Building TU Delft. In this measurement, the threshold is set to be -60 dB. Table 3 below represents the measurement results.

Table 3. Signal Measurement Results

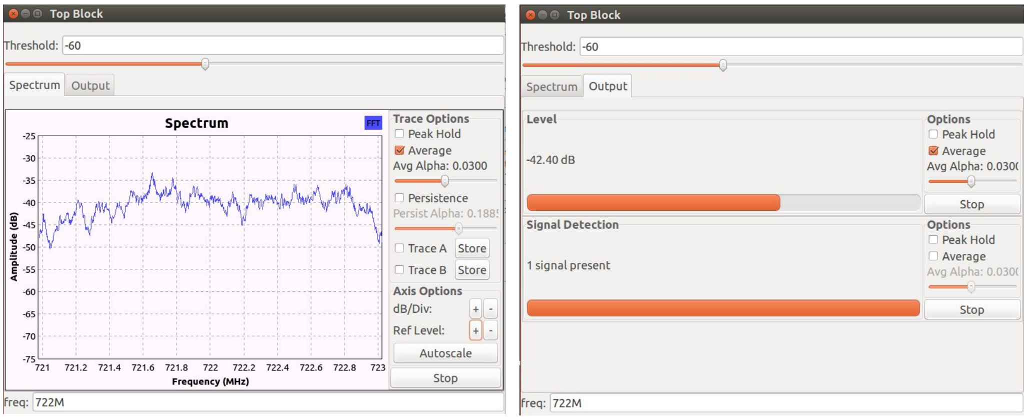
			Rontgenweg, Delft (51.999156, 4.357706)		TU Delft (EWI 2nd floor) (51.999044, 4.374250)		Total Average & Std. Deviation
Frequency User	**Center Freq (MHz)**	**Freq. Range (MHz)**	**Detection**	**Average Level (dB)**	**Detection**	**Average Level (dB)**	
RTS Bouquet 1	722	718–726	✔	-57.4	✔	-56.7	Average: -59.95 dB Std. Deviation: 9.32
NTS1 Bouquet 2	698	694 – 702	✔	-53.3	✔	-57.6	
NTS2 Bouquet 3	762	758 – 768	✔	-57.6	×	-65.8	
NTS3 Bouquet 4	498	494 – 502	✔	-46.8	✔	-49.4	
NTS4 Bouquet 5	522	518 – 526	✔	-53.4	✔	-48.9	
Unknown #1	480	1 carrier	✔	-71.6	✔	-70.6	
Unknown #2	600	1 carrier	✔	-76.8	×	-77.5	
Unknown #3	795	791.5 – 800.5	✔	-53.2	✔	-49.7	
Unknown #4	805	801.5 – 810.5	✔	-59.6	×	-65.2	
Unknown #5	815	811.5 – 820.5	✔	-68.6	✔	-59.4	
Empty #1	550	-	×	-79.1	×	-78.5	Average: -75.83 dB Std. Deviation: 3.16
Empty #2	650	-	×	-78.7	×	-78.2	
Empty #3	750	-	×	-77.5	×	-77.4	
Empty #4	850	-	×	-77.9	×	-78.7	
Empty #5	478.5	-	×	-73.6	×	-72.9	
Empty #6	479.2	-	×	-72.7	✔	-66.8	
Empty #7	489.6	-	×	-76.7	✔	-74.3	
Empty #8	504	-	×	-73.9	×	-74.6	
Empty #9	506	-	✔	-75.3	×	-75.5	
Empty #10	604.8	-	×	-78.4	×	-75.9	

In this measurement, 10 frequencies in which signals exist and 10 frequencies in which no signals exist are measured. The duration of measurement for each frequency is 10-15 s in order to wait for the signal to be stable every time the frequency changed. The average of noise level is indicated by the level where no signal present. Therefore, the receiver's average noise level is -75.83 dB.

4.1. Signal Detection

Picture 5 (left) is a spectrum of DVB-T signal of RTS Bouquet 1 that has center frequency of 722 MHz. From Picture 5 (right), the average receive signal level bar indicates -42.4

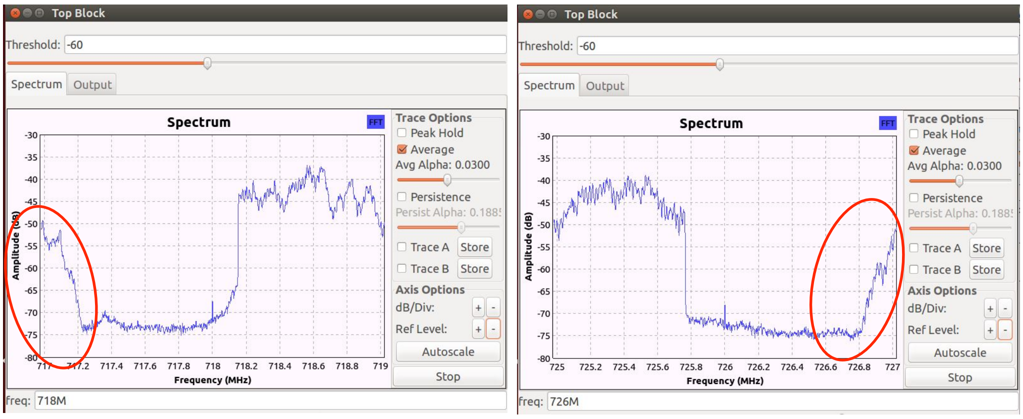
dB which is above the threshold level (-60 dB). Therefore, the detector detects a signal present in such frequency.



Picture 5. Detection of Signal in Frequency 722 MHz

The level -42.4 dB represents the instantaneous average level of the received level on spectrum. It fluctuates every time due to signal fluctuation. Therefore, in order to get both spectrum and receive level more stable, the average in trace option has to be enabled. For this case, the average alpha parameter equals to 0.03. The smaller the average alpha value, the less the signal fluctuates.

The spectrum plot in Picture 5 only displays 2 MHz parts of DVB-T spectrum. It doesn't display the full spectrum mask because the window span (wide) is only 2 MHz while the DVB-T spectrum bandwidth is 8 MHz. However, the lower edge and upper edge of the signal are also captured in Picture 6 in order to observe the start frequency and stop frequency of a DVB-T signal. Since the bandwidth allocated for a DVB-T carrier is 8 MHz, a DVB-T signal with center frequency 722 MHz has frequency range 718 – 726 MHz.

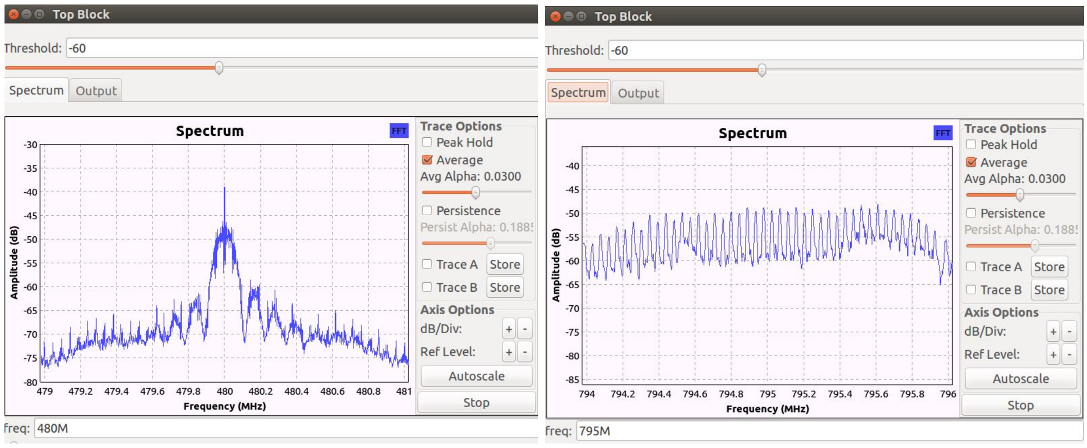


Picture 6. DVB-T Signal Edge Detection

From Picture 6, we can observe that the signal's peak starts from 718.15 MHz and lasts to 725.75 MHz. Hence the signal's bandwidth is around 7.6 MHz which is less than 8 MHz maximum bandwidth of DVB-T system. However if we can lower the noise level, we will observe the signal foot, in which the signal start and stop, so that the measured bandwidth will be around 8 MHz. The signal inside the red line circle is not a real signal. It appears in FFT GUI Sink due to the windowing.

However, there are some unknown signals detected in the television broadcast band. Those signals appear on 480 MHz, 600 MHz, 795 MHz (791.5 – 800.5 MHz), 805 MHz

(801.5 – 810.5 MHz) and 815 MHz (811.5 – 820.5 MHz). Picture 7 displays the signal detection in frequency 480 MHz and 795 MHz.

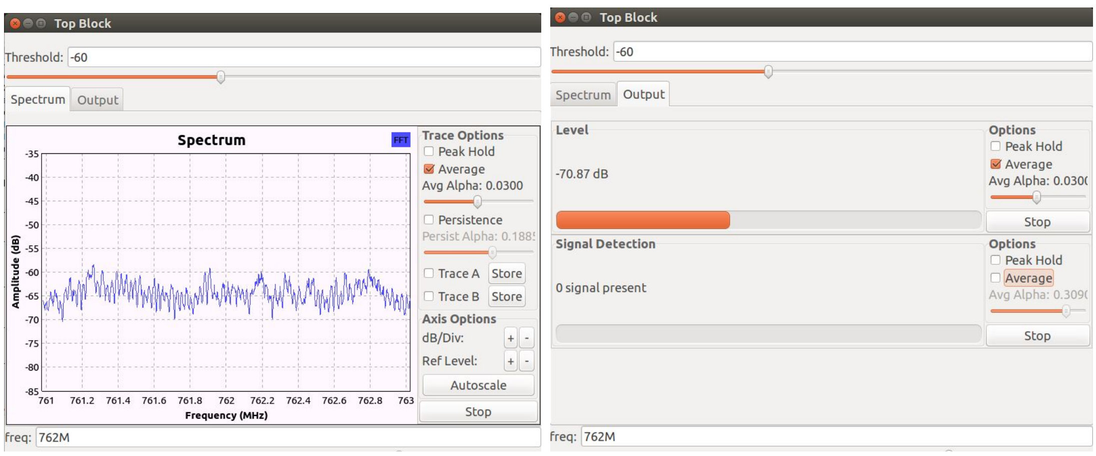


Picture 7. Detection of Unknown Signal in Frequency 480 MHz (left) &795 MHz (right)

Signals in frequency 480 MHz and 600 MHz are the carrier signals with high receive level with bandwidth around 200 kHz. Based on the Nederland Frequency Database [4], there is no user that is allocated in those frequencies. Since the detector unable to demodulate those signals, hence the content of those signals can't be identified. Therefore, it is assumed that those signals might be an unlicensed signal or an intermodulation product of other signals. On the other hand, signals in frequency 795 MHz, 805 MHz and 815 MHz are the signals with high receive power level (around -55 dB) and large bandwidth (around 9 MHz). Based on the Nederland Frequency Database [4], such frequencies are allocated for Wideband Frequency Modulation (WFM) radio purpose.

4.2. Signal Missed Detection

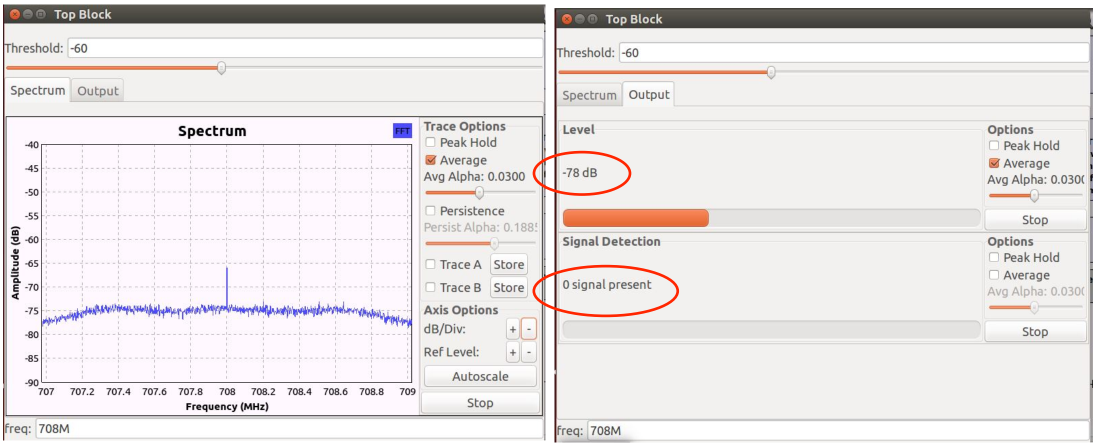
Signal missed detection occurred if the detector is unable to detect the presence of the signal. It might because of the low reception of the signal receive level or the error in detection process. In order to mitigate this problem, lowering the threshold can be a solution. Picture 8 shows the example of missed detection of signal in frequency 708 MHz.



Picture 8. Missed Detection of DVB-T Signal in Frequency 762 MHz

4.3. No Signal Presence

If there is no signal received in particular frequency, the detector will decide that there is no signal presence. In this case, the receiver only detects the noise level. Picture 8 shows the example of “0” detection in frequency 708 MHz.



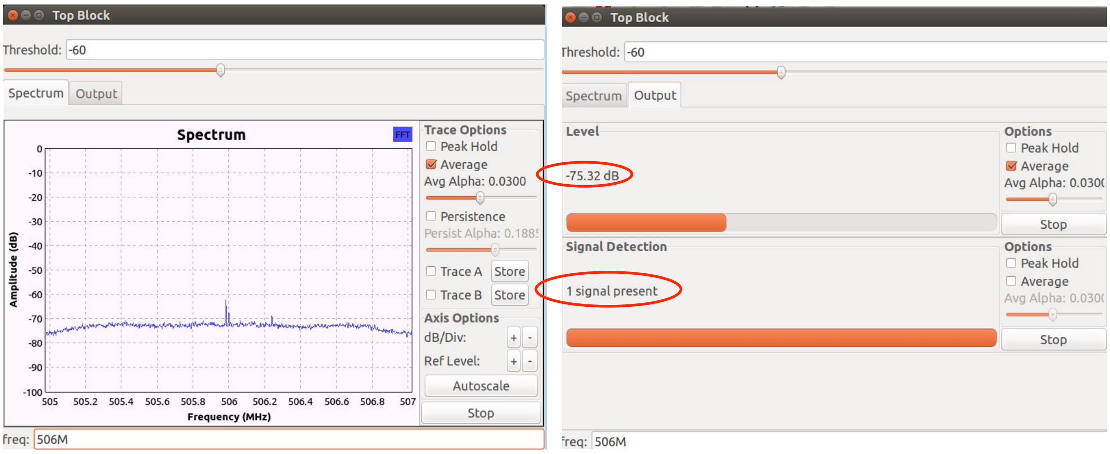
Picture 9. No Detection of Signal in Frequency 708 MHz

In Picture 9, we can see that there is a signal presence with a very narrow bandwidth in the center frequency. Its level is around 8 dB above the noise level. This kind of signal always present in the center frequency, even when the frequency is changed to the DVB-T signal’s frequency. However, this signal becomes seamless when there is a DVB-T signal presence in the band because its level is smaller than the received level of DVB-T signal, which can reach 20 dB above the noise level.

Nevertheless this kind of signal is not a real signal in the air. It is generated by a baseband processing of RTL-SDR Source and is appeared in GUI FFT Sink. Its level that is relatively higher than the noise level may cause a false alarm in the detection process. Therefore, we have to be careful in selecting the threshold value. We have to choose the threshold value that is closest as possible to the average noise level but slight above the level of this baseband signal.

4.4. False Alarm

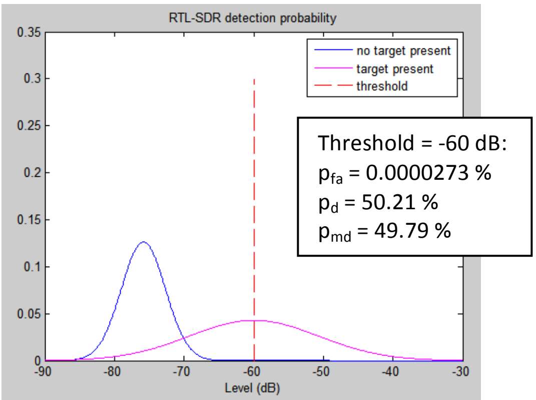
The presence of aforementioned carrier in the center of frequency can affect the signal detection process. False alarm occurred when there is no signal presents in particular frequency but the system detects that there is a presence of a signal. One of the solutions to reduce the probability of false alarm is by increasing the threshold value. Picture 10 describes the example of false alarm detection.



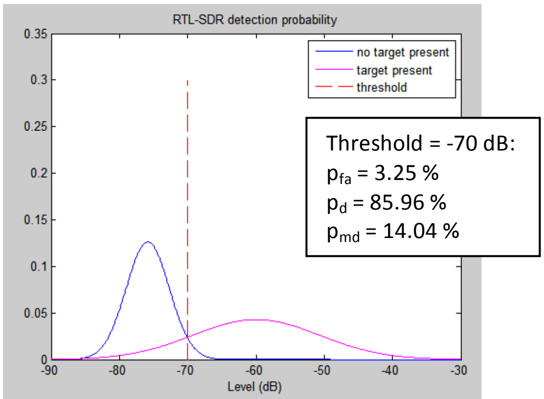
Picture 10. False Alarm Detection of Signal in Frequency 506 MHz

4.5. Receiver Performance

In the measurement, -60 dB threshold value is used. The distribution of target presence and no target presence for threshold of -60 dB is plotted in Picture 11. Both target present and no target present are plotted using normal distribution by using average and standard deviation value from the measurement in Table 3.



Picture 11. Receiver Performance for Threshold = -60 dB



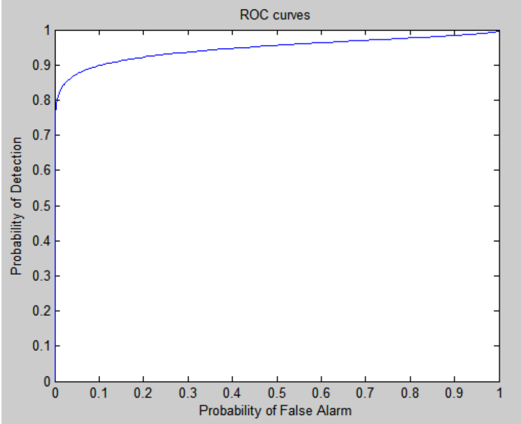
Picture 12. Receiver Performance for Threshold = -70 dB

From the calculation in MATLAB [MATLAB script attached in Appendix], although the probability of false alarm is very close to 0%, the probability of detection is only 50.21 %. It means that 49.79 % of the presence signals will be missed detected by the receiver. In cognitive radio system, if a receiver fails to detect the presence signal on particular frequency, it will consider such frequency to be empty. Hence it might transmit in that frequency and interfere the existing user.

In order to get the optimal value of both probability of detection and probability of false alarm, the threshold has to be lowered. In this case, the threshold should be set at the intersection point of no target present distribution and target present distribution. In Picture 12, we can see that at the intersection point, the threshold level is -70 dB. By decreasing the threshold to -70 dB, the probability of detection becomes 85.96 % and the probability of false alarm becomes 3.25 %.

The detection performance of a receiver is affected by probability of detection and probability of false alarm. Both performance parameters are illustrated by ROC curves.

Picture 13 illustrates the ROC curve of the receiver. The working area of the receiver is under that ROC curve.



Picture 13. ROC Curve of Receiver

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Conclusion

Signal sensing can be performed by the energy detection method. In order to get more accurate detection result, multiple receivers have to be located in several different places in the area of interest. By performing cooperative sensing, the detection result of each receiver can be combined and be analyzed to produce a better detection result. Moreover, more measurement samples have to be taken in order to get the better data for determining the receiver characteristic.

There is a trade-off between probability of detection and probability of false alarm. Threshold affects both probability of detection and probability of false alarm. Therefore, the optimal threshold value should be picked carefully in order to minimize the false alarm probability and maximize the detection probability.

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] http://gnuradio.org/redmine/projects/gnuradio/wiki
[4] http://www.pc5e.nl/downloads/scanner/Frequenties%20Nederland%20totaal%20(PDF).pdf

Appendix

MATLAB script that is used for calculating the probability of detection and false alarm as well as plotting the target presence distribution and ROC curve:

```
% no target present distribution mean = -75.83 dB & stdev = 3.16
Pnotarget = makedist('Normal','mu', -75.83,'sigma',3.16);
% target present distribution mean = -59.95 dB & stdev = 9.32
Ptarget = makedist('Normal', 'mu', -59.95,'sigma',9.32);
threshold = -60 ; % threshold -60 dB
Pfa = 1 - cdf(Pnotarget,threshold) % prob of false alarm
Pd = 1 - cdf(Ptarget,threshold) % probability of detection

figure(1);
plot(Level,Pnotarget.pdf(Level));
hold on
plot(Level,Ptarget.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(Pnotarget,Level); % prob of false alarm
Pd_ROC = 1 - cdf(Ptarget,Level); % prob of detection

figure(2);
plot(Pfa_ROC,Pd_ROC);
title('ROC curves')
ylabel ('Probability of Detection')
xlabel ('Probability of False Alarm')
```