GNU Radio project

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1 Introduction

Radio spectrum utilization is always a heated topic not only because it is a limited resource but also due to most frequencies in spectrum are in the unused status, even though all of them have been allocated. Hence, dynamical identifying signal presence in particular frequencies becomes the most critical factor for realizing optimized band utilization. Cognitive radio, which is designed as a signal presence detector in a certain frequency, starts transmitting as long as a particular frequency is sensed as absence. Therefore, interference with other frequency can be avoided by this method and effectively improves the band utilization ratio at the same time. This project is based on spectrum sensing which is a partial function of cognitive radio. Our task is to use spectrum sensing technology to obtain awareness about the spectrum usage and existence of primary users under varying channel conditions. One of spectrum sensing method, energy detector is achieved in this project with the tools of RTL-SDR 2838 dongle and GNU radio. These tools compose of a spectrum sensing system performing DVB-T signal and white space detections. Furthermore, operating characteristics of receiver are discussed and receiver performance is valued by using Matlab.

The structure of this report is divided into six sections. In the following section, relevant background knowledge of this project is depicted. Implementation details are described in section 3. Experiment results and receiver performance analysis are characterized in section 4. Conclusion is derived in section 5 and followed by reference in section 6.

2 Background

2.1 White space

Radio spectrum represents electromagnetic spectrum from 3 Hz to 3000 GHz and different parts of radio achieves different radio transmission technologies and applications. The transmission, emission and/or reception of radio waves for specific telecommunication purposes of radio waves is strictly regulated by the nation administration. Users of these frequencies are defined as primary users who have higher priority or legacy rights on the usage of a specific part of the spectrum. For the sake of making good use of this limited resources, frequencies which are not being used by licensed services are made available for unlicensed users (Secondary users). Nevertheless, the employment of secondary users must vacate the frequency when primary users become active. This allocation method is considered as a reasonable and effective way to optimize band utilization. Besides, secondary users must not interfere the transmitting of primary users. As a result, reliably detecting primary users is the key challenge of making use of white space.

In this project, spectrum sensing based on Digital Video Broadcasting-Terrestrial channels covers a range from 48.25-863.25MHz. DVB-T is a European-based consortium standard for the broadcast transmission of digital terrestrial television. Five channels(one bouquet and four commercial channels[1]) and white space detection are the mainly targets in this investigation.

2.2 Spectrum sensing

As aforementioned definition, spectrum sensing aims at detecting the activation of primary users in a geographical area. Typically, the performance of spectrum sensing is evaluated by the probability of detection and probability false alarm. Cooperative sensing is one of spectrum sensing method which can solve problems that arise due to noise uncertainty, fading and shadowing. It can solve the hidden primary node problem and decreases false alarm rate significantly. Energy detector, another kind of spectrum sensing method, is known as the most common method due to its low complexity. Besides, there are also some other methods, like waveform-based sensing, radio identification based sensing. But the one we implementing in this detection is energy detector method.

However, spectrum sensing is not the only way for improving band utilization. Database approach has been admitted as another effective method and a very promising technology. For example, Google is working with industry and regulators to make more spectrum available by using a database to enable dynamic spectrum sharing. Secondary users not only can browse spectrum of any area but also can sign up to use the database for research or commercial needs.

3 Implementation

3.1 Energy detector

In this report, we adopt energy detector method to detect the channel frequencies from 478MHz to 862MHz. The detection system construction flow is showed in figure 1. Input signal is transformed from time domain into frequency domain by Fast Fourier Transformation (FFT) process. The second block derive energy by square two-dimension. Last block implies that a decision is made by comparing with threshold. Average power level above threshold is determined as a signal present, showed as "1", oppositely, "0" means no signal at this frequency because the average power level lower than threshold. Threshold is independent of the modulation type of a signal but depends on the noise variance, and estimation of noise variance is an important issue, slight inaccuracies may degrade performance. Thus, threshold selection is a key challenge in this project.

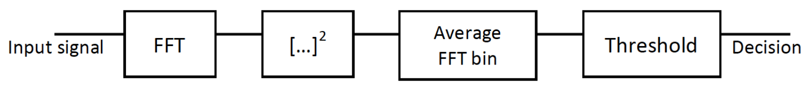


Figure 1: Energy Detector Implementation in Frequency Domain[2]

3.2 RTL-SDR 2838 dongle & GNU radio

Two tools, RT-SDR 2838 dongle and GNU radio are used in this project. GNU radio is a open source software which provides signal processing blocks to implement SDR and signal processing systems. RTL-SDR 2838 dongle is a DVB-T dongles based on the Realtek RTL2832U. It can be used as a cheap SDR since the chip allows transferring the raw I/Q samples to the host, which is officially used for DAB/DAB+/FM demodulation. And it could auto-scan the bandwidth of 6/7/8 MHz signal. This dongle is used as the receiver to detect 20 frequencies in this project. The received signal goes through a predefined GNU radio block based on figure 1. Energy detection GNU radio block for this research is showed in figure 2.

It is notable that as increasing gain is an effective way of increasing receiving power of antenna, RF Gain and IF Gain in the following block are set as 30 dB. This decision is made after several failure experiments due to the very weak signal received by dongle. Received signal power increases significantly after this modification.

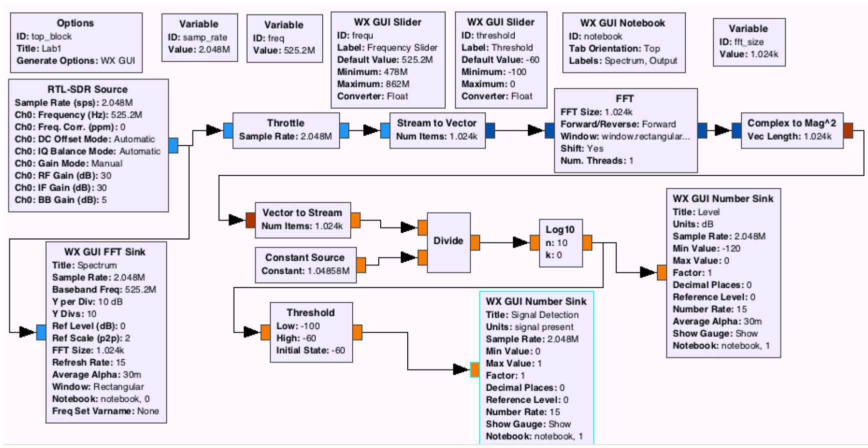


Figure 2: Energy Detector Implementation in Frequency Domain[2]

4 Results and Analysis

Experiment results are recorded in the four following tables. Table 1 and 3 contains 10 frequencies in which signals exists and 10 frequencies in which no signals exists, respectively. It can be seen that there are the DVB-T Multiplexer operators in Delft area. The first bouquet is a free channel which without receiving encryption and bouquet 2,3,4 and 5 are all commercial channels which are all the same over the Netherlands. Threshold for these two measurement are the same, -60 dB. In each experiment, average level, peak level, frequency range are measured. Center frequency, average level is showed in table 1 and table 3.

In table 1, we detect 20 frequencies threes times a day, 10am, 4pm and 11pm, at a fixed location. It takes around 20 seconds to record result for each frequency, because the output statistics can only be marked when spectrum graph reaches a relative stable status. Then we calculated the total average level and standard deviation for first 10 frequencies and the others, respectively. The result of calculation is showed in table 2.

Table 3 represents a different measurement method. In this experiment, measurements are performed in different places but at a similar time. Similarly, 20 frequencies are under detection. And total average level and standard deviation are showed in table 4.

Table 1: Signal Measurement Results(same spot)

Rotterdamseweg 139A Location: 52.00079 4.36892							
		10AM		4PM		11PM	
Frequency User	Center Freq (MHz)	Detection	Average Level(dB)	Detection	Average Level(dB)	Detection	Average Level(dB)
RTS Bouquet 1	722	✓	-55	✓	-55	✓	-56
NTS1 Bouquet 2	698	✓	-59	✓	-51	✓	-50
NTS1 Bouquet 3	762	✓	-49	×	-62	✓	-55
NTS1 Bouquet 4	498	✓	-56	✓	-50	✓	-55
NTS1 Bouquet 5	522	✓	-58	✓	-51	×	-73
Unknown #1	480	×	-71	×	-72	×	-73
Unknown #2	600	×	-75	×	-75	✓	-51
Unknown #3	795	✓	-40	✓	-41	✓	-43
Unknown #4	805	✓	-53	✓	-59	✓	-59
Unknown #5	815	✓	-59	✓	-53	✓	-58
Empty #1	550	×	-76	×	-74	×	-76
Empty #2	650	×	-75	×	-75	×	-75
Empty #3	750	×	-77	×	-75	×	-76
Empty #4	850	×	-74	×	-75	×	-76
Empty #5	478.5	×	-74	×	-71	×	-75
Empty #6	479	×	-77	×	-69	×	-73
Empty #7	504	×	-74	×	-75	×	-73
Empty #8	505.984	×	-74	×	-75	×	-75
Empty #9	604.8	×	-76	×	-75	×	-75
Empty #10	617.2	×	-75	×	-74	×	-76

Table 2: Total average & Standard deviation

	Total Average &Std.Deviation
Signal exists	-57.2333, 9.4575
No signal exists	-74.66667,1.59861

Table 3: Signal Measurement Results

		TU Library 52.00262 4.37546		TU Library Location: 51.99843 4.35409	
Frequency User	Center Freq (MHz)	Detection	Average Level(dB)	Detection	Average Level(dB)
RTS Bouquet 1	722	✓	-52	✓	-58
NTS1 Bouquet 2	698	✓	-54	✓	-58
NTS1 Bouquet 3	762	×	-72	✓	-58
NTS1 Bouquet 4	498	✓	-66	✓	-54
NTS1 Bouquet 5	522	×	-64	✓	-55
Unknown #1	480	×	-73	×	-67
Unknown #2	600	×	-71	×	-72
Unknown #3	795	×	-64	✓	-41
Unknown #4	805	×	-73	✓	-59
Unknown #5	815	×	-72	✓	-46
Empty #1	550	×	-74	×	-75
Empty #2	650	×	-74	×	-75
Empty #3	750	×	-76	×	-76
Empty #4	850	×	-76	×	-77
Empty #5	478.5	×	-72		-63
Empty #6	479	×	-70	✓	-69
Empty #7	504	×	-75	×	-61
Empty #8	505.984	×	-75	×	-64
Empty #9	604.8	×	-75	×	-63
Empty #10	617.2	×	-75	×	-63

Table 4: Signal Measurement Results(same spot)

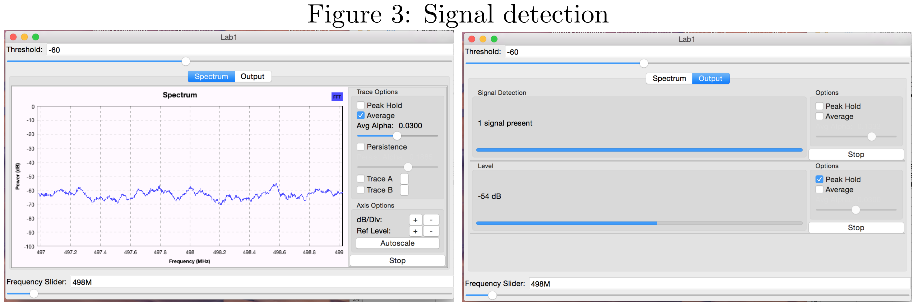
	Total Average &Std.Deviation
Signal exists	-61.45, 9.2117
No signal exists	-69.95,7.61233

4.1 Spectrum & Output Analysis

4.1.1 Signal detection

Start with the flowgraph introduced in figure 2, a window along with spectrum and output are generated showed in figure 3. Threshold and frequency slider bars allow us to dynamically adjust the threshold and detect frequency. Figure 3 shows the spectrum and output when central frequency is 498MHz and threshold is -60 dB. The first graph stems from flowgraph output. This trace is showed in average mode. In the second graph, current average level is -54dB which is larger than threshold, so "1 signal present" showes. Users can also change the average mode to peak mode, from which a higher power is always measured compare to average level in this flowgraph block.

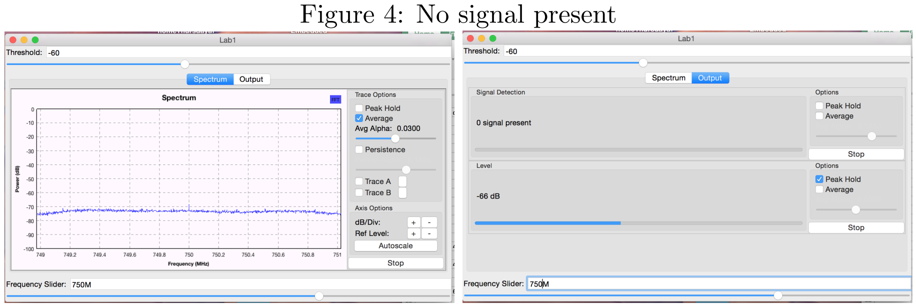
Figure 3: Signal detection



4.1.2 No signal present

In figure 4, we can see that all the average level from 749 MHz to 751 MHz are lower than threshold. Consequently, the output is -66dB below threshold. So on output interface there is no signal present can be seen.

Figure 4: No signal present



4.1.3 Signal missed detection

Figure shows the case of a frequency channel considered as absence, but in fact the users on this channel are active. In the second figure, we can see output shows -75dB and no signal present. But on spectrum do exist signal on this channel. Sliding frequency slider can observe the start and the end of signal. Generally, this case happens when the signal is weak and with low power(most signal power on this channel are under threshold). The solution could be lower threshold or slightly increase gain of antenna.

Figure 5: Signal missed detection

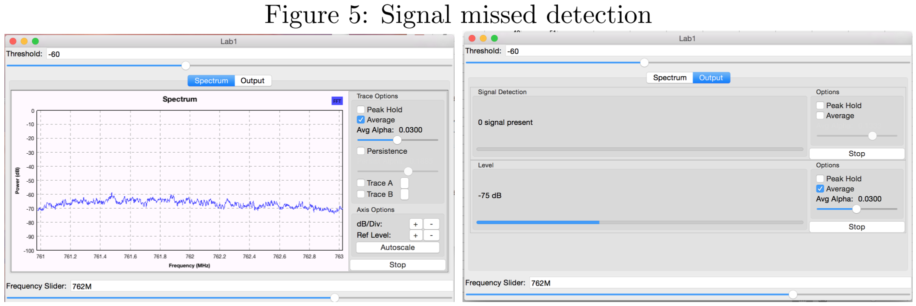
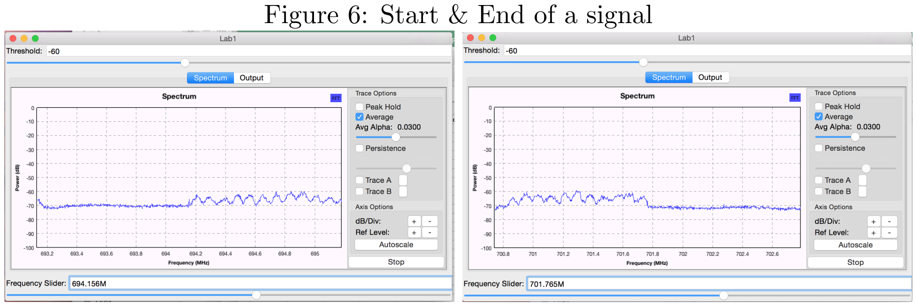


Figure 6 shows the start and end of a signal.

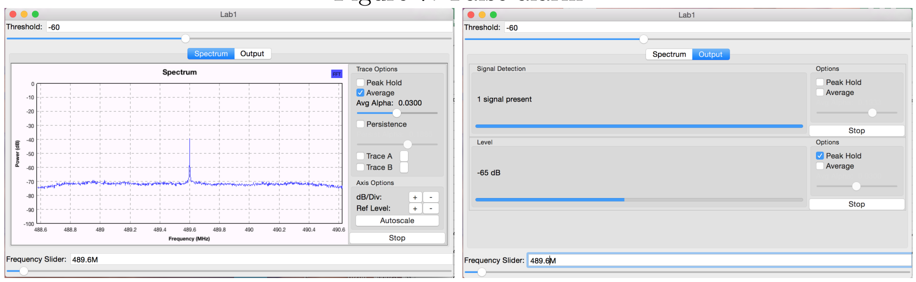
Figure 6: Start & End of a signal



4.1.4 False alarm

A false alarm occurs where a non-target event exceeds the detection criterion and is identified as a target[3]. This is often due to the influence of the carrier in the center of a frequency. Figure 6 depicts a false alarm example when central frequency is 489.6MHz. A interfering carrier can be seen in the center.

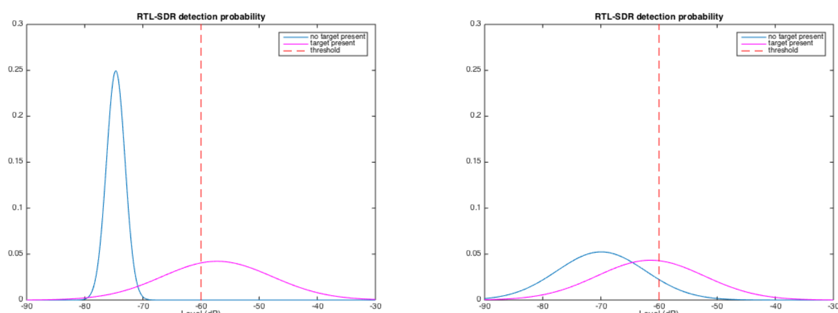
Figure 7: False alarm



4.2 Receiver performance

As we aforementioned description: condition 1 means the experiment operated in a same spot but at three different time. Condition 2 is operated at two different spots but at a nearly simultaneous time. Both conditions set threshold as -60dB. By using the total average level and standard deviation statistics at section 4, normal distribution graph are plotted by Matlab showed as figure 8. Results of false alarm probability, detection probability and miss detection probability of two conditions calcutaed by matblab are listed in table 5.

Figure 8: Receiver performance



For the first condition, we can see that false alarm probability, detection probability and miss detection probability are 2.7287e-07, 0.6151, 0.3849, respectively. We can say receiver has a good performance when threshold is -60dB if we only take false alarm probability into account. Nevertheless, the detection performance of receiver is valued by detection probability and false alarm probability. The detection probability is only 0.6151 which means 31.49% signal cannot be detected under this threshold. Primary users will be evidently interfered by secondary users because no signal detected under the situation where primary users are active. For condition 2, false alarm up to 9.56% and detection probability is only 43.75% even lower than condition 1, so we have to say that receiver performance is even worse when threshold in -60dB on condition 2.

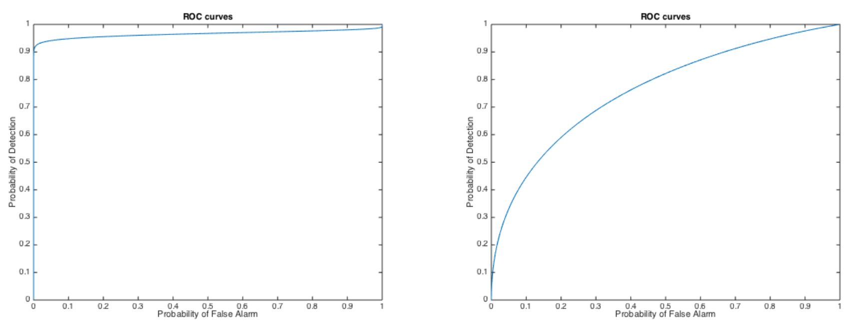
Table 5: Receiver Performance

	Condition 1	Condition 2
Threshold	-60dB	-60dB
Px_{fa}	2.7287e-07	0.0956
Px_{d}	0.6151	0.4375
Px_{md}	0.3849	0.5625

So it can be concluded that setting threshold as -60dB is not a wise choice for both conditions. According to the low current detection probability for both condition, we should go for a lower threshold in future research.

Furthermore, ROC curve of the receiver on two conditions are represented in figure 8. ROC curves depict performance parameters and below curve part is the working area of receiver. It is obviously that working area is much more less on condition 2.

Figure 9: Receiver performance



5 Conclusion

Energy detection provides a less complex method for spectrum sensing but accompanied with threshold selection problem. In this method, receiver performance is evaluated by detection probability and false alarm probability at the same time. Lower threshold increases detection probability but also false alarm probability. Spectrum cannot be effectively utilized with high false alarm probability. Higher threshold decreases detection probability and also false alarm. However, low detection probability misleads secondary users and cause interference to primary users.

6 Reference

[1] DVB-T frequencies https://nl.wikipedia.org/wiki/DVB-T-frequentieshttps://nl.wikipedia.org/wiki/DVB-T-frequenties

[2] Rizqi Hersyandika 4410106, Delft University of Technology, GNU Radio Project Report

[3] False alarm, WiKi pedia, https://en.wikipedia.org/wiki/False_alarm