Experimental Implementation of Spectrum Sensing Using Cognitive Radio

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Abstract

Cognitive radio (CR) is designed to detect available frequency bands/channels. Spectrum sensing plays a critical role in CR with energy detection being the most common method. In our paper, we implement energy detection using GNU Radio and USRP boards as a test-bed. Specifically, energy detection is performed by using blocks in GNU Radio Companion (GRC) to calculate the energy of a present signal and compare it against a threshold to determine whether or not the channel is occupied by a signal. Extensive experiments are conducted and sensing performance including false alarm and misdetection is analyzed as well.

1. Introduction

As the frequency spectrum continues to become more and more crowded, especially under 3 GHz, it is becoming more challenging to allocate available frequency bands to future applications. On the other hand, there are still a lot of licensed areas of the spectrum which are underutilized. Cognitive Radio Network (CRN) is one promising way of utilizing the spectrum to the utmost efficiency. CR gives us this opportunity because it is able to detect unused portions of the frequency spectrum and share with unlicensed users without causing harmful interference to licensed users.

There are three fundamental steps to successfully implement a CRN: spectrum sensing, spectrum sharing, and spectrum management. These three steps will be briefly introduced as follows.

1.1. Spectrum Sensing

Spectrum sensing is the process in which secondary users (SU) (unlicensed users of the spectrum) obtain information about the spectrum usage so that interference will not occur with primary users (PU) (licensed users) [3]. Experimental implementation of spectrum sensing will be discussed in this paper. There are some common approaches of spectrum sensing. Energy detection (ED) is one such sensing method, which will be used due to simplicity of implementation and most importantly, no need for prior knowledge of the signal is required. ED is designed to sense the level of energy of a potential signal and compare it against a threshold. Figure 1 shows the block implementation of ED. A signal is first sent through a band pass filter and then integrated over the square of the signal. This value is compared against a pre-define threshold and then a decision is made to determine whether or not it reaches the energy level is high enough to be considered a signal.

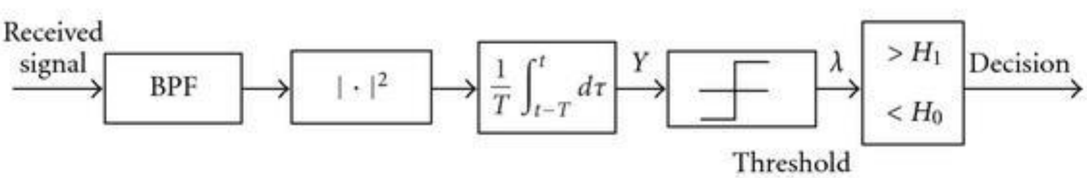

Figure 1: Energy detection blocks

*H_1 indicates that a signal is present, while H_0 indicates absence of signal

Matched filter detection is another common method of spectrum sensing, which is designed to maximize signal-to-noise ratio when a user has prior knowledge. The matched filter is expressed as [4]:

$Y[n] = \sum_{k=-\infty}^{\infty} h[n-k]x[k]$---Eq. 1

'X' is the unknown signal and 'h' is the impulse response. The block diagram of matched filter detection is also passed through a band pass filter which is then sent through a matched filter which is shown by Equation 1 and then a decision is made to determine whether or not a signal is present.

Besides energy detection and matched filter detection, Cyclostationary detection is also received a wide attention in the research community. It heavily relies on the periodicity of a signal to identify whether or not a primary user is present. Cyclostationary feature detection performs much better under low SNR, and does not require silence of CR users. Cyclostationary feature detection, however, requires prior knowledge and has very high computation complexity [4].

1.2. Spectrum Sharing and Spectrum Management

With sensing results from the spectrum sensing process, spectrum sharing is the simultaneous usage of specific radio frequencies in a certain geographical region [5]. Transmit power has to be minimized to eliminate interference to nearby signals.

Spectrum management is the process of capturing the best available spectrum and limiting the interference between users. Note that spectrum sharing and spectrum management are left for future research. The main focus of this paper is on spectrum sensing.

1.3. Experimental Implementation of Energy Detection

In this paper, we perform experimental implementation of spectrum sensing, in which Energy Detection (ED) is employed. The test-bed consists of universal software radio peripheral (USRP) N200 (figure 2) with daughterboard (XCVR2450) (shown on the left) and GNU Radio Companion (GRC), run on Ubuntu 14.04 (Linux-based operating system), for creating energy detection blocks. Using this test-bed, we expect that we are able to implement ED successfully, i.e., detecting spectrum status correctly. .

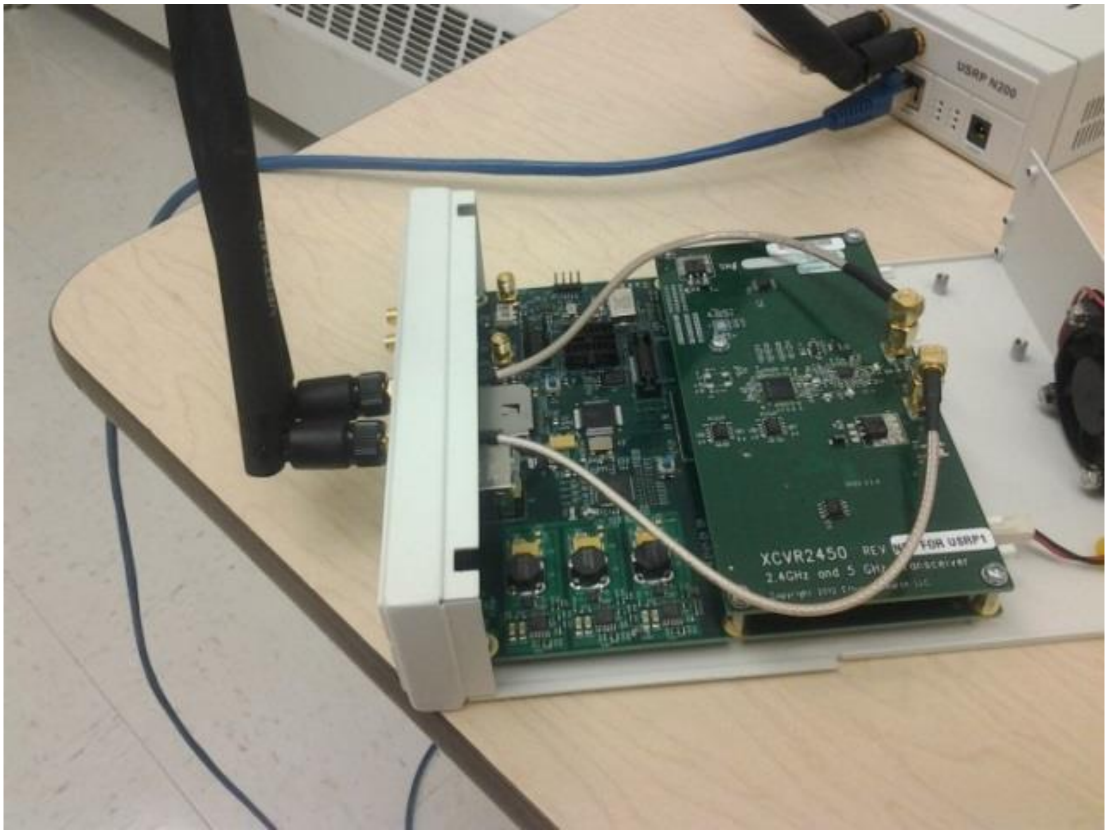

Figure 2: USRP N200

After conducting experiments, the sensing performance including both false alarm and misdetection is analyzed. The evaluation of false alarm and misdetection heavily relies on a pre-defined threshold. Misdetection probability refers to the probability that a signal is in fact present, but the signal amplitude does not meet the requirements as defined by the threshold. In other words, the signal is not detected correctly and hence the channel is perceived idle. Setting of a threshold too high causes misdetection to sharply rise. False alarm on the other hand refers to something that is not a signal (such as noise), but it will meet the energy requirements as set by the threshold. Setting of a threshold too low can be a major concern. Setting of a threshold is therefore important as far as quality is concerned.

Setting a threshold in ED can be somewhat difficult if a low signal-to-noise ratio is present. As will be seen in the results portion of the paper, a threshold was set to -60dB, which results in a very high percentage of both misdetection and false alarm. Eliminating both misdetection and false alarm probability must be overcome before implementation can take place.

2. Broader Impact

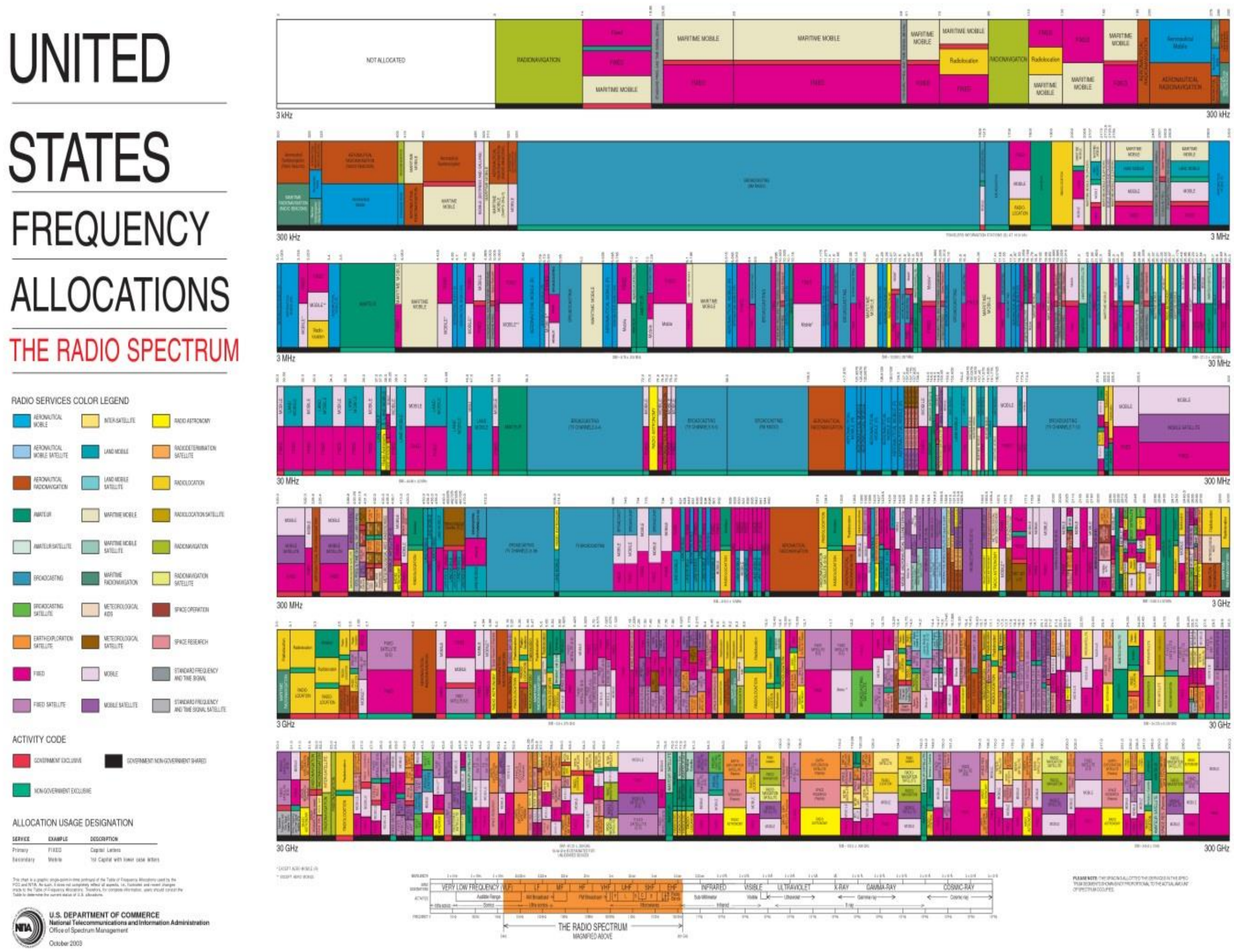

Figure 3: Frequency allocations [6]

As we continue to add more wireless devices (smartphones, tablets, computers, etc.), we are making our lives easier and more enjoyable, but problems arise with an increasing demand for these products. It is becoming increasingly difficult to find the optimum frequency band. Cognitive radio is envisioned promising to solve this problem by dynamically allocating the area of the spectrum, which are getting increasingly compact and also makes use of the areas which lay mostly vacant. The frequency spectrum is much like land in that one cannot simply make more land, but instead making the most of what is given can go a long way. Figure 3 shows the allocation of different parts of the radio spectrum, which is becoming increasingly cluttered, making adding more advances in wireless communication more difficult. Being able to use the frequencies whenever they become available by the use of CR is becoming more relevant.

3. Procedure

In this paper, we set up a test-bed using the USRP N200 and daughterboard (XCVR2450) as shown in Figure 2. After connecting this to a computer and installing GNU Radio Companion (GRC) on Ubuntu 14.04, we could proceed to carry out the experiment. After successfully writing a few lines of code, we are able to visually see what sort of signal is being received, but also what effect noise can have on a signal as well. Figure 4 shows what sort of noise is present at a given time in our experiment. Without a signal being received, the amount of noise appears to be very even and with a very low energy (in dB).

Here is another graph (Figure 5), but this time a signal is being received at 2.4499 GHz with a considerable amount of microwave noise. This microwave noise is generated from a microwave which is situated between the receiver and the transmitter. The SNR is relatively low in this picture which will undoubtedly cause a higher than acceptable misdetection and false alarm probability.

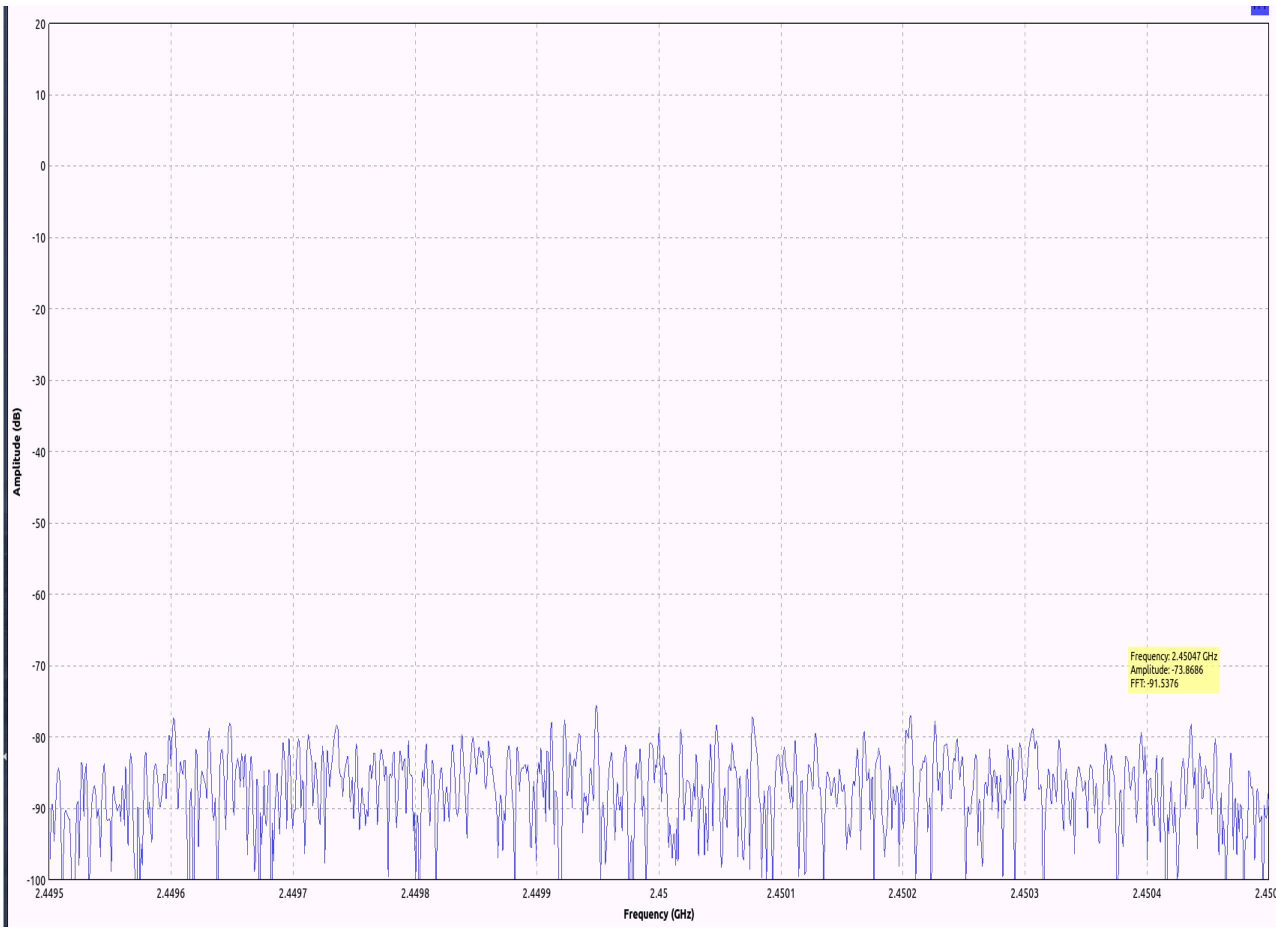

Figure 4: Noise Only

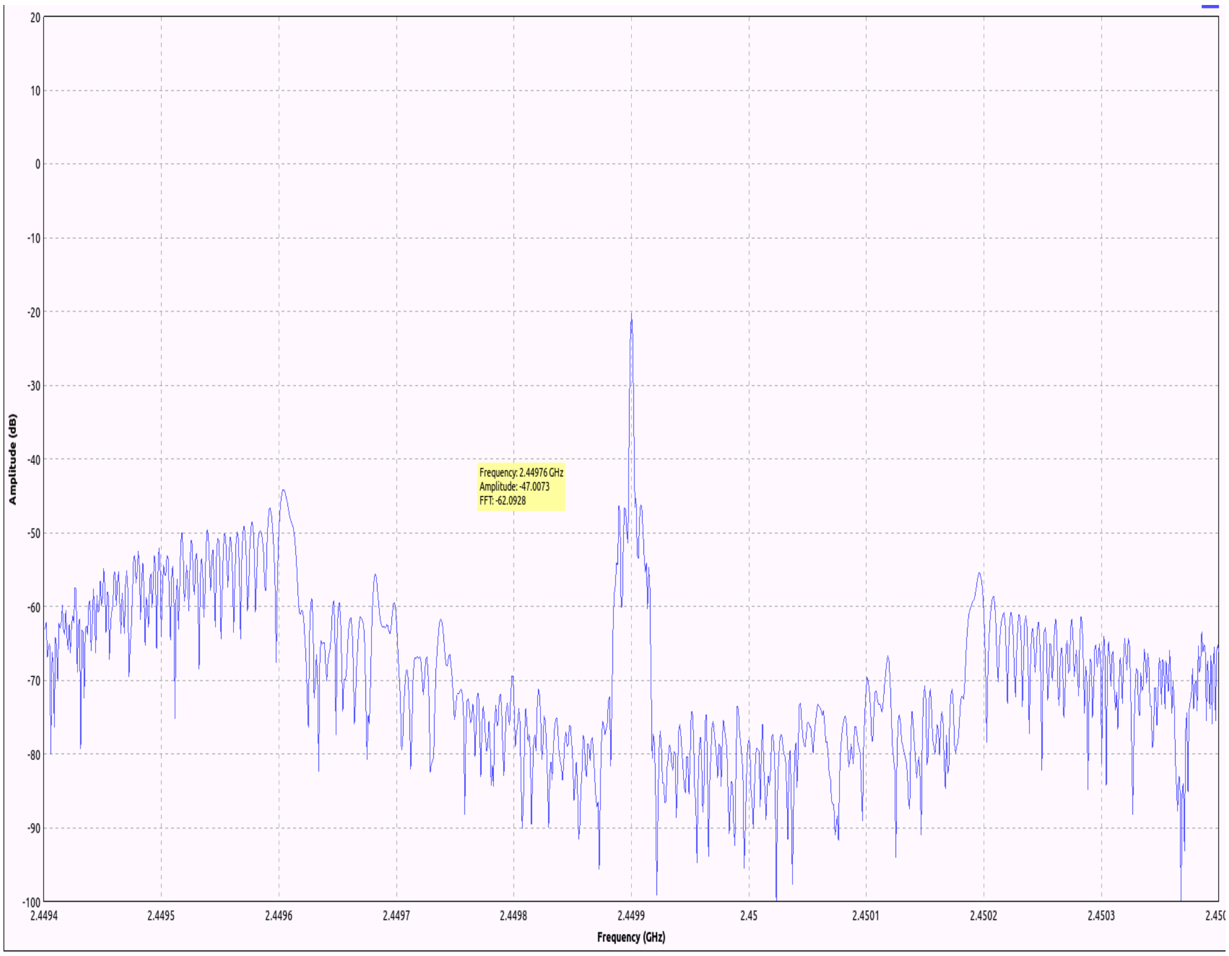

Figure 5: Signal received at 2.4499 GHz with low SNR

To effectively create a threshold, many experiments must be done using the same set parameters, such as noise level (in our case we used a microwave oven), frequency, and distance. Experiments could also be done at longer distances while varying levels of noise. After doing the experiment ten times, we could finally move on to setting various thresholds from -20db to -90db to analyze sensing performance. Two metrics, i.e., probabilities of false alarm and misdetection, are measured. The blue line in figure 6 shows an example of what a potential threshold could be, so that misdetection and false alarm probability are minimalized. This

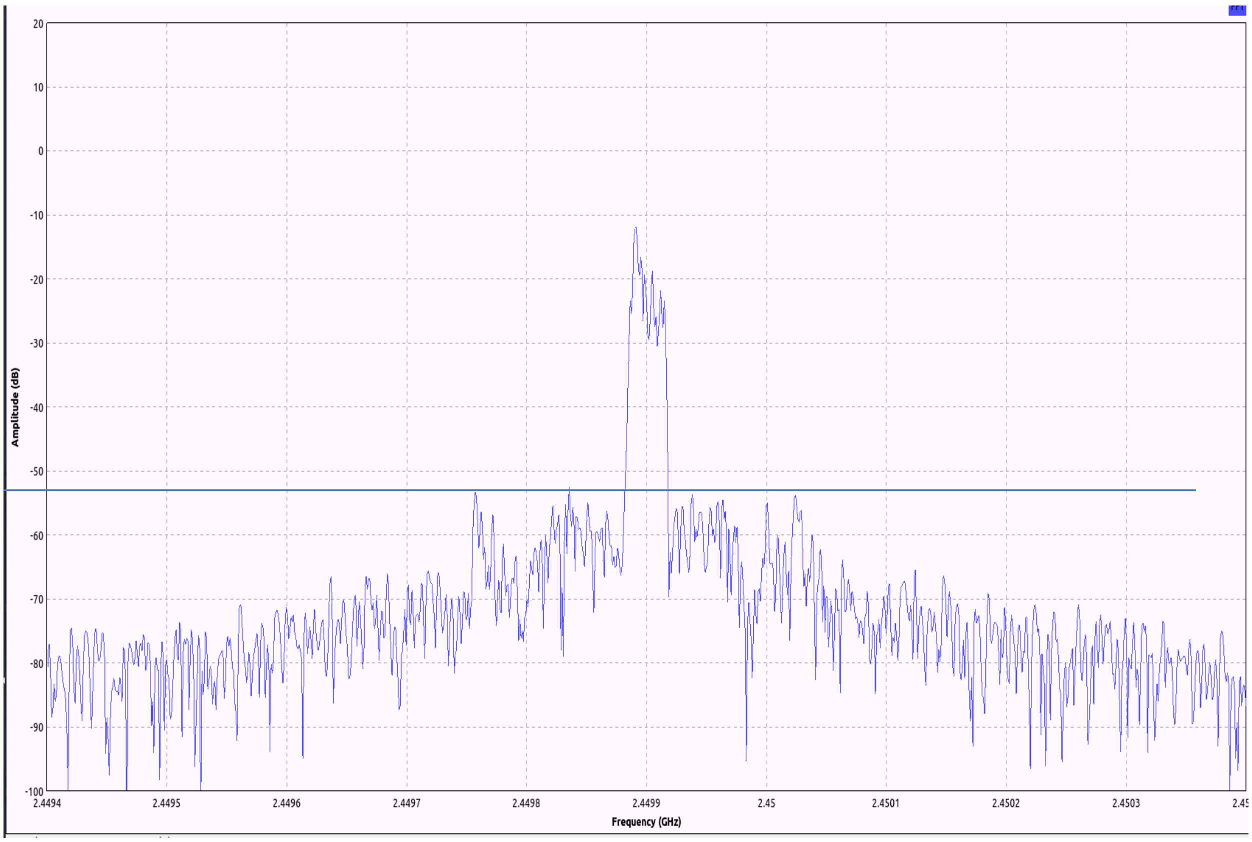

Figure 6: Example threshold at -50 dB

threshold (-50dB), though, would not be equal on all graphs because both the power and the noise will very in all graphs. Once thresholds are created, it must be determined at which point gives us the lowest combined misdetection and false alarm probability

4. Results

Threshold (dB)	Probability of Misdetection	Probability of False Alarm
-20	1	0
-25	1	0
-30	1	0
-35	0.8	0
-40	0.7	0
-45	0.5	0
-50	0.5	0
-55	0.4	0.1
-60	0.2	0.2
-65	0	0.5
-70	0	0.6
-75	0	0.7
-80	0	0.9
-85	0	1

Table 1: Samples of probabilities of false alarm and misdetection vs threshold

After running the ten samples, and determining different intervals (5dB apart), the following excel sheet is created which gives the threshold level followed by the percent of false alarm and misdetection at said threshold. From this (table 1), Figure 7 is plotted to give a visual understanding of the trends of false alarm and misdetection.

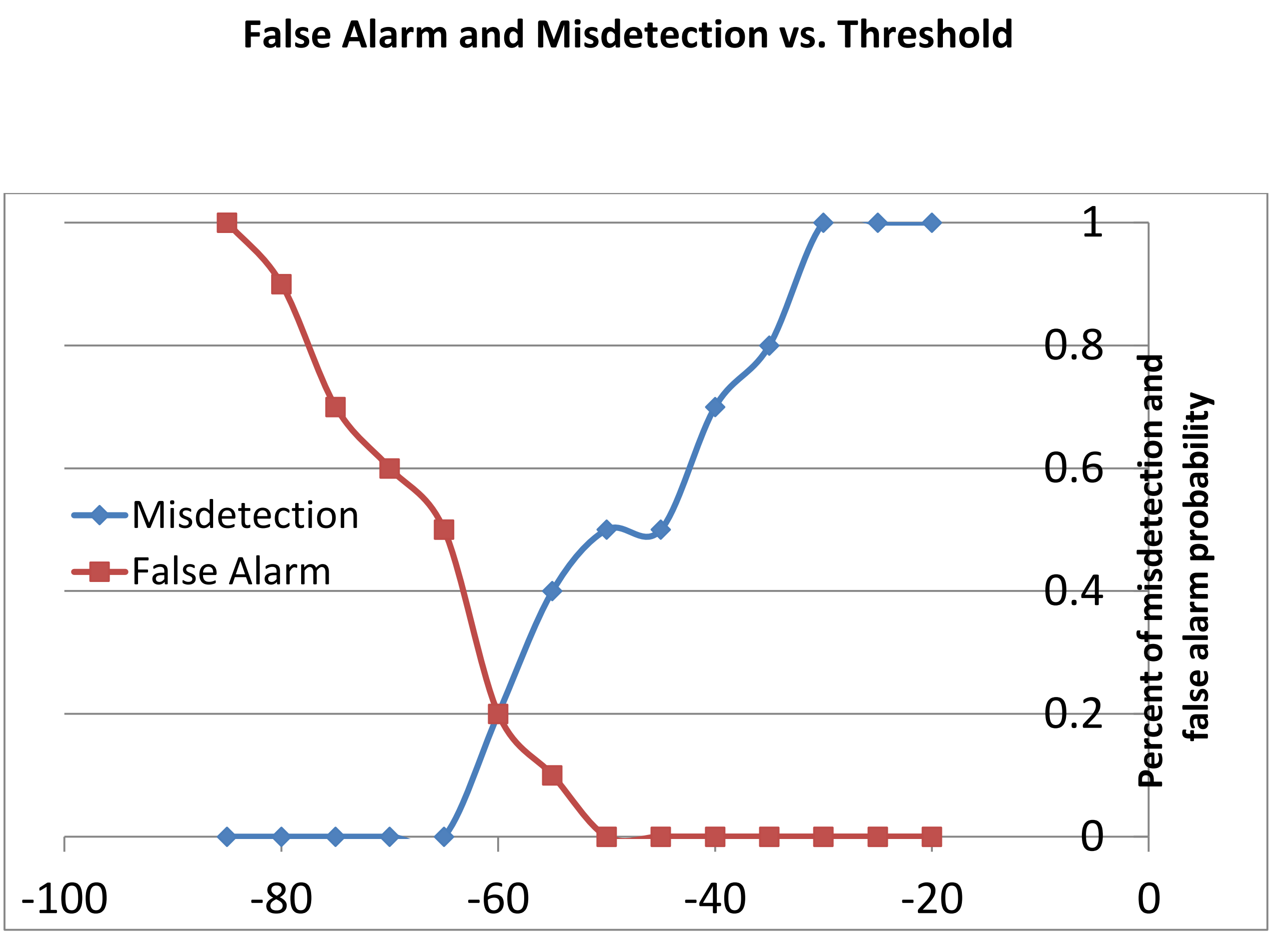

Figure 7: False alarm and misdetection probabilities vs. thresholds (in dB)

It appears that -60db is the optimum level for misdetection and false alarm probability, but at the intersecting point, this number is 20%, which is much higher than expected. The sensing results are affected by several factors. For instance, currently, only 10 samples are collected and the result is expected better with more samples. Different environments with varying levels of noise will without a doubt have impact on the probability of false alarm and misdetection. Also the distance of the receivers will have an effect on the SNR.

5. Discussion

We have conducted extensive energy detection (ED) experiments using USRP and GNU radio. Some promising preliminary results are obtained followed by sensing performance analysis. However, many problems still exist with ED. As shown in Section 4, with microwave noise (Wi-Fi and other interferences are included); -60db appeared to be the optimum threshold with an exuberant amount of probability of misdetection and false alarm. There have been many proposals to lowering this percentage of misdetection and false alarm probability. One method, proposed in [2] was to implement two thresholds which instead of simply choosing one threshold and accounting only for energy levels above that point. The double threshold method would account only for values in between the two thresholds and make a decision from that point.

One method that we are strongly considering though, is a method which accounts for both bandwidth and energy detection. In this method, the bandwidth of a signal would have to be within a certain range and anything outside of that would not be considered a signal (noise by definition has unlimited bandwidth, so this would eliminate most noise) which in theory leads to a lower false alarm and misdetection probability. Future work will be done on proving whether or not this method works as well in practice as it does theoretically.

6. Conclusion

Energy detection is a common approach of spectrum sensing. In this paper, we have implemented energy detection by setting up a test-bed using USRP and GNU radio. Sensing results show that currently we obtain 20% misdetection and false alarm probability, which is by no means perfect. More efforts should be put forth to improve the sensing performance. In future, we will propose new approach based on energy detection and conduct more experiments.

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