Spectrum Sensing for Improved Cognitive Networks

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***Abstract*—As more electronics require wireless technology, the already crowded wireless channels become even more congested. The limited cellular frequency bands have led to disruptive signal interference in high traffic areas. Airline companies have also halted cellular 5G deployment because of the possible interference with their mission critical signals sent over the air. This affects telecommunication companies and their customers, essentially all cell phone users, particularly those in urban and densely populated areas. This team implemented a spectrum sensing Software-Defined-Radio system to find clear channels in heavy traffic areas. This will be done via energy detection methods and other methods will be explored such as a cyclo-stationary auto-correlation method. Implementing a spectrum sensing system was the first step towards more efficient spectrum utilization, otherwise known as cognitive networking. It allowed for improved communication in cities during emergencies or events with large volumes of people. By efficiently allocating different sub-bands, users can communicate with little to no interference.**

I. Introduction

Spectrum sensing is one of the fundamental features of cognitive networks and even finds its purpose in electronic warfare [6]. Cognitive networks solves the problem of overcrowded wireless channels, by searching for unoccupied channels from which it can transmit through. This is especially important when more than one signal attempts to transmit over the same frequency[3]. Air Force Research Laboratory and Wright Brothers Institute have provided two National Instrument Universal Software Radio Peripheral (USRP-2901) for this research. These Software Defined Radios, or SDRs, have the ability to receive and transmit over-the-air signals, while connected to a host computer [5]. The programming of the Spectrum Sensing system was all done on the host computer, using MATLAB as the primary platform for research.

Related works describe different methods for spectrum sensing: energy detection, cyclo-stationary, and matched filters. Energy detection and cyclo-stationary were specifically studied; energy detection being an easily programmable function, and cyclo-stationary due to its high efficiency in both accuracy and time to detect [1]. Energy detection can operate either by monitoring a band of frequencies, or by monitoring a moving window of a much wider band. The former was explored first due to it having less variables than the sweeping detection method. The cyclo-stationary method uses auto-correlation principles, finding major disruptions in input signals and the signal's previous state.

II. Related Work

Cognitive networks are still being researched for its benefits in communication networks. Many of the research and text available describe spectrum sensing as an essential component of cognitive networks. They also mention the same three methods: energy detection, matched filter, and cyclo-stationary [1][3][4][7][8]. Studies in these topics continues to be of great importance as many communication systems go wireless. Bands of frequencies become occupied by an increasing number of transmissions from different sources. When different signals transmit at the same time over the same range of frequencies, the receiver receives a mixture of these signals, and will experience interference. One way to combat this is to raise the noise floor level, which will allow the receiver to focus on transmissions with energy levels over this "noise floor," or by increasing the signal-to-noise ratio. MATLAB exercises found in *Cognitive Radio - An Enabler for Internet of Things* [7] provided a plot for energy detection and its probability of detection for a range of signal-to-noise ratios. Although this was created with simulated data, it shows the importance of having a high enough ratio for best results.

III. Our Solution

With the research from related works, the energy detection method was implemented following Figure 2. A noise floor threshold must be established before proceeding with spectrum sensing. This establishes a threshold from which the system can determine whether a band of frequencies are occupied or not. The pre-determined band of frequencies was then monitored for any signals with energy levels above this threshold.

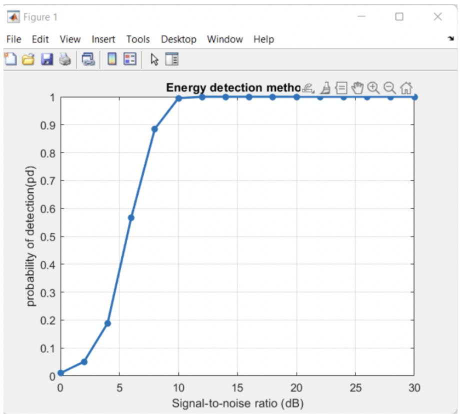

Fig. 1. Probability of detection for Signal-to-Noise ratio

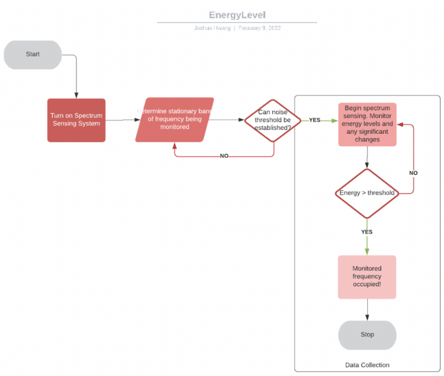

Fig. 2. Energy Level Detection

A. Implementation Details

Each USRP 2901 require a computer from which it can be programmed. The two radios were connected via USB 3.0 to two different laptops. MATLAB was the primary platform used in this research. The goal of this experiment was to observe data received by one USRP-computer system, while noting any changes in the observed data. MATLAB offers a USRP software defined radio class from which signals can be transmitted and received. The received data comes in the form of an array of complex numbers as a result of quadrature phase shift keying modulation [9].

One of the USRP 2901s was first used to receive data from over-the-air signals centered on 2.4500 GHz while the second radio was absent and turned off. This receiver collected data at a rate of 362 samples per frame, which is the length of the complex array. With no transmissions from the second USRP, a baseline was found for an ”unoccupied” channel. Two methods were used for detecting channel occupation: energy detection and auto-correlation. Results proved to be as expected for energy detection and auto-correlation.

Energy detection was implemented as simply as possible by taking the magnitudes of the complex numbers and plotting it. This will give a peak amplitude at the center of its plot with the plot starting from 0 on the x-axis. Auto-correlation was implemented with a built-in MATLAB function finding the

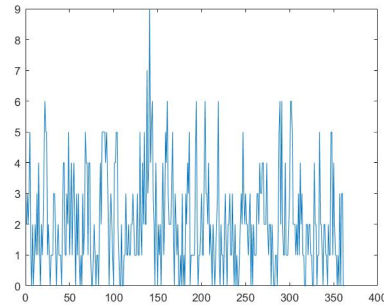

Fig. 3. Magnitude of received signal over unoccupied channel

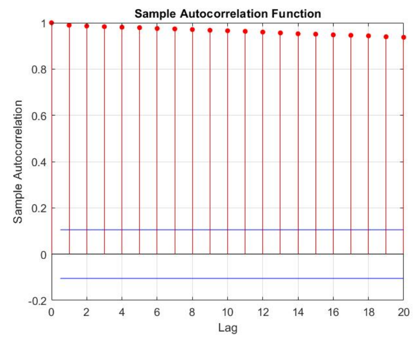

Fig. 4. Auto-correlation of received signal over unoccupied channel

difference between the output at one instance and the output before that one instance. For an absent channel, this would theoretically show no major disruptions in the transmitted signal’s amplitude, and a significant change when a signal is detected.

The second stage of experiments was the same setup as before, but with the second USRP-2901 transmitting over the same center frequency of 2.4500 GHz. This part remains incomplete which is explained further in the following sections. A Quadrature Phase Shift Keying signal was continuously transmitted from the transmitting radio. This is indicated by a red light on the front facing interface.

B. Performance Analysis

The proposed spectrum sensing system developed did not show any major differences in energy level detection and auto-correlation when a signal was transmitted compared to when a signal was not being transmitted. This should be further evaluated because this is an indication of errors in the data collection when receiving on an unoccupied frequency, or errors in the interpretation of displayed data. In the following section, ”Future Directions,” there are several recommendations to reiterate the experiment with better results. The expected outcome was to see a much larger magnitude at the center frequency during transmission when compared to an unoccupied channel. The auto-correlation expected outcome was a large difference between any of the lags. More specifically, the plotted lag would see an absolute difference between the lags.

IV. Future Directions

The results disagreeing with the expected changes when a signal was transmitted over the monitored band of frequencies requires more iterations with better controlled variables. Fundamentals of spectral analysis and its applications in MATLAB should be revisited as that being possibly the point of failure in the expected results. Matched filter is another method which is often mentioned in most publications, and an algorithm we haven't formulated yet [7][8].

Once these algorithms succeed, signal-to-noise ratio and its effect on data collection should be studied. A high enough SNR may help to remove noise and improve the detection of channel occupancy. Cyclic spectrum sensing is another topic which can be further studied. This involves signal processing of signals which vary periodically. The current MATLAB code for this project includes cyclic spectral analysis, although the results did not provide any significance with our current knowledge [2].

Each platform available: GNU Radio, MATLAB, and LabVIEW, have their benefits. MATLAB is a great tool for simulations and calculation heavy applications. It is also the only platform which requires two separate MATLAB sessions for the use of two radios on one host computer. The other platforms do not have these issues. LabVIEW is the best tool for visualizing the operations of the software defined radio. Lastly, GNU Radio offers the most features and is the only free open-source platform.

Finally, this spectrum sensing system can be developed into a cognitive radio network. With a fully functioning spectrum sensing system, the cognitive radio network requires only a few more features. This is to transmit and receive signals in any environment through frequency hopping, modulation classification, and signal relaying.

V. Conclusion

Spectrum sensing continues to be an important topic of research especially with its use in cognitive radio networks. Cognitive networks have the ability to dynamically route signals over unoccupied channels, but they cannot know a band of frequencies is unoccupied without spectrum sensing. This shows the importance of continuing the advancement of technology in spectrum sensing.

A functioning cognitive radio network with minimal features would be a major accomplishment, as can be seen from the development of only spectrum sensing. This ideal cognitive radio should be able to transmit and receive data in almost any hostile environment. Accuracy in spectrum sensing and modulation classification are very important to make this happen, and if this project is continued, it is highly recommended to address this first.

References

[1] Anurag & B. Singh A. Ranjan. Design and analysis of spectrum sensing in cognitive radio based on energy detection, 2016. 2016 International Conference on Signal and Information Processing (IConSIP).

[2] Jerome Antoni. Cyclic spectral analysis, 2022.

[3] Ezio Biglieri. *Principles of Cognitive Radio*. Cambridge University Press, 2012.

[4] Almohanad S. Fayez Charles W. Bostian, Nicholas J.Kaminski. *Cognitive Radio Engineering*. Institution of Engineering and Technology (The IET), 2016.

[5] F. Lind. Software defined radio, 2019.

[6] R. Poisel. *Modern Communications jamming prinicples and Techniques*. Artech House, Norwood, MA, 2nd edition, 2011.

[7] et al. R. Kalidoss. *Cognitive Radio - An Enabler for Internet for Internet of Things*. River Publishers, 2017.

[8] Kandeepan Sithamparanathan. *Cognitive Radio Techniques*. Artech House, 2012.

[9] Alan Wolke. #170: Basics of iq signals and iq modulation & demodulation - a tutorial, 2014.