Algorithm and Experimentation of Frequency Hopping, Band Hopping, and Transmission Band Selection Using a Cognitive Radio Test Bed

Hasan Shahid
Stevens Institute of Technology
Hoboken, NJ, United States
hshahid126@gmail.com

Yu-Dong Yao
Stevens Institute of Technology
Hoboken, NJ, United States
yyao@stevens.edu

***Abstract*—A cognitive radio test bed was designed and developed using an Ettus Research USRP and GNU Radio. Experimentations were performed to test cognitive radio algorithms and features of frequency hopping, band hopping, and transmission bad selection for interference avoidance. A secondary user device scans a 200 MHz frequency range, which contains five 40 MHz bands. The secondary user performs frequency band selection based on system noise and interference characteristics. Experiments demonstrate good channel selection and interference avoidance performance.**

Keywords—software-defined radio; cognitive radio

I. Introduction

Cognitive radio is a software-defined radio based technology that can automatically adjust its transmission and reception parameters so that wireless communication can operate more efficiently (i.e., avoid interference). Cognitive radio technology has many potential uses for military and commercial purposes, including cellular phones and tactical radios. Future generations of wireless communications standards, such as 5G, are expected to incorporate the use of cognitive radio [1].

The two main functions of cognitive radio are spectrum sensing and spectrum access. Sensing scans the wireless spectrum for information about which channels are being used and which are free. This is usually done by cognitive radio terminals, secondary users. Through spectrum allocation, devices choose certain operating channels based on a specific algorithm which takes into account relative position of devices, signal strength, noise level, and probability of interference [2].

This paper presents the development of a software-defined cognitive radio test bed. The system implements both transmission and reception functions. While transmitting a signal, a certain frequency range around the transmission frequency is scanned. If other signals are detected, the cognitive radio adjusts its transmission frequency to avoid causing interference. The system also defines a primary band in which the radio will transmit if there are no outside signals within this frequency range.

The remainder of this paper is organized as follows. The second section describes the model of the cognitive radio network used. The third section describes the transmission algorithms implemented. The fourth section describes the experimental setup used. The fifth section describes the experiments performed to test the system and results of these experiments. Finally, the sixth section includes a conclusion and recommendations for further work.

II. System Model

Consider a network of cognitive radios with N channels, M cognitive devices, and P sources of interference (malicious or not). Assume that the sum of M and P is less than N.

Each device requires an operating channel to transmit and receive signals in the network. The devices have both transmission and reception capabilities. A device will scan the spectrum of the network in order to determine the optimal channel for operation. This channel should not be occupied by other users (primary or secondary users) or interference sources and should have a relatively low noise level. This will allow the device to operate at a higher signal-to-noise ratio, ensuring good transmission and reception performance.

After selecting a preferred channel of operation, each device must continue to scan the channel for outside signals and be capable of switching channels to avoid interfering with these outside signals.

III. Transmission Algorithms

The test bed developed contains four major algorithms: frequency hopping, band hopping, band selection, and new band assignment.

A. Frequency Hopping

The frequency hopping algorithm allows the cognitive radio to avoid interference from malicious users. This algorithm forces the device to change its transmission frequency after a specified time interval. This can be a security measure to prevent malicious users from locating the signal and thus jamming the signal and blocking communication or spying on the signal and accessing classified information being transmitted. This algorithm was implemented in a previous test bed developed at Stevens Institute of Technology [3]. A flowchart of the frequency hopping algorithm is depicted in Fig. 1.

B. Band Hopping

Whereas frequency hopping prevented other users from interfering with the signal from the cognitive radio, the band hopping algorithm prevents the cognitive radio from interfering with signals from other users. If the maximum power at a certain frequency exceeds a specified threshold, the device identifies this as another user and the transmission frequency is forced to jump to a new band. While scanning, the radio skips its own transmission frequency so that it does not confuse its own signal for a signal from another user. The band hopping algorithm assumes that the cognitive radio is a secondary user. Other devices are treated as priority users in that band (primary or secondary users). If another signal is detected, the cognitive radio jumps to a different band to yield to the priority user. Like the frequency hopping algorithm, this algorithm was implemented in a previous test bed developed at Stevens Institute of Technology [3]. A flowchart of the band hopping algorithm is depicted in Fig. 2.

C. Band Selection

The band selection algorithm is the first to run in the test bed program. The cognitive radio scans the spectrum and measures the average noise and interference level in each band. The device then chooses the band with the lowest noise and interference level as the ideal band for operation and then begins transmission within this band.

D. New Band Assignment

Once the ideal band is chosen, it is integrated into the frequency and band hopping algorithms. Frequency hopping runs during transmission and, if another signal is detected, the transmission frequency will jump to a different band. The band selection algorithm will then run again and the device will jump to the chosen band. The exact process of this algorithm depends on protocols defined for yielding to priority users. For example, if the secondary user must leave the band immediately, it will jump to a random band before carrying out the band selection algorithm and jumping to the ideal band. If the secondary user is allowed some time before yielding, it can run band selection algorithm without unnecessarily jumping to a random band. The system described in this paper assumes that the secondary user must yield to the priority user immediately. A flowchart of the band selection algorithm and new band assignment is depicted in Fig. 3.

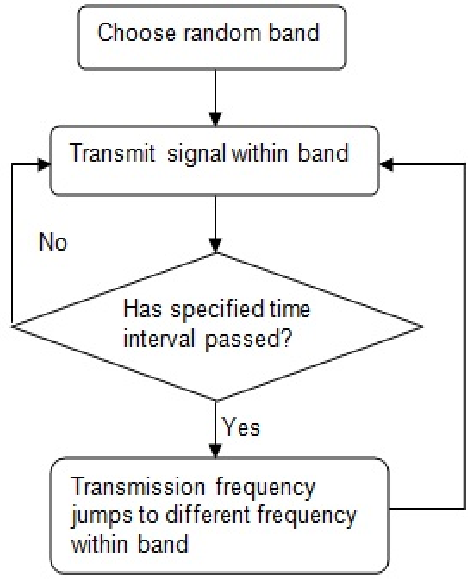

Fig. 1. Frequency hopping flowchart.

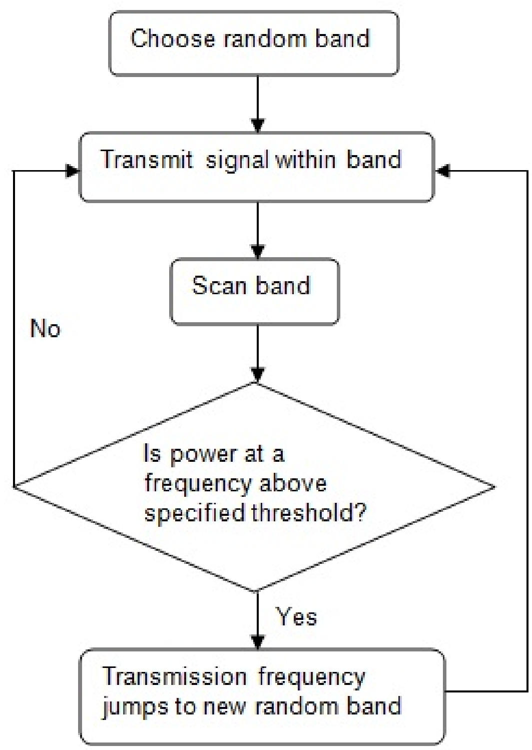

Fig. 2. Band hopping flowchart.

IV. Experimental Setup

The experimental setup used in the project consisted of four major components: a laptop running GNU Radio, a Universal Software Radio Periphery (USRP), a signal generator, and a spectrum analyzer. A block diagram of the setup is depicted in Fig. 4.

A. GNU Radio

GNU Radio is an open source software that is widely used as a programming platform for software-defined radio systems. It can be used to simply send and receive a signal as well as incorporate various signal processing functions. Applications are written in Python, while signal processing blocks are written in C++. Newer versions of GNU Radio include GNU Radio Companion, a graphical user interface which allows users to create flow graphs which in turn, generate source code in Python. GNU Radio 3.6.1 was used to program the USRP. As stated before, the algorithms for frequency hopping and band hopping were implemented in a previous test bed developed at Stevens Institute of Technology. Like the

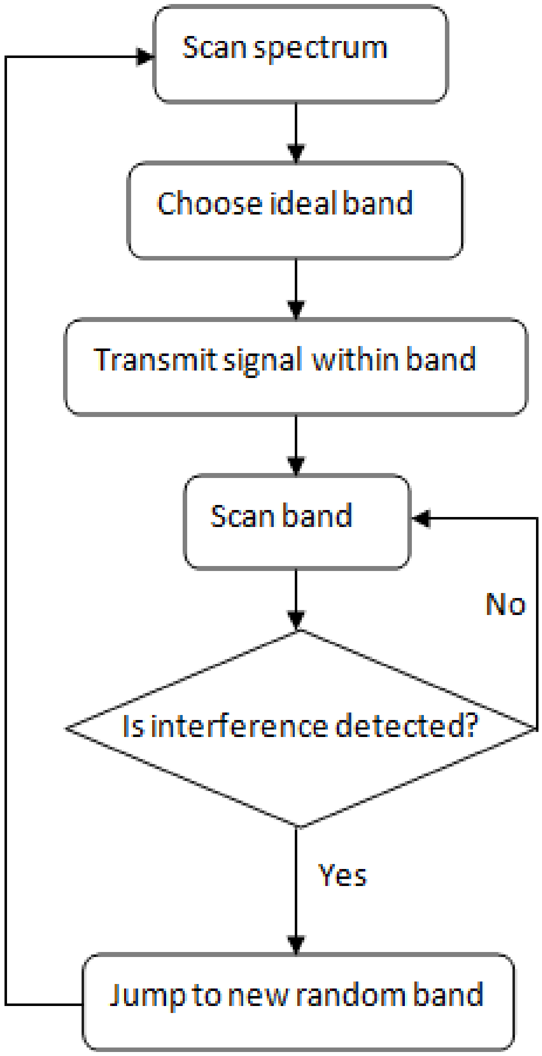

Fig. 3 Band selection and new band assignment flowchart.

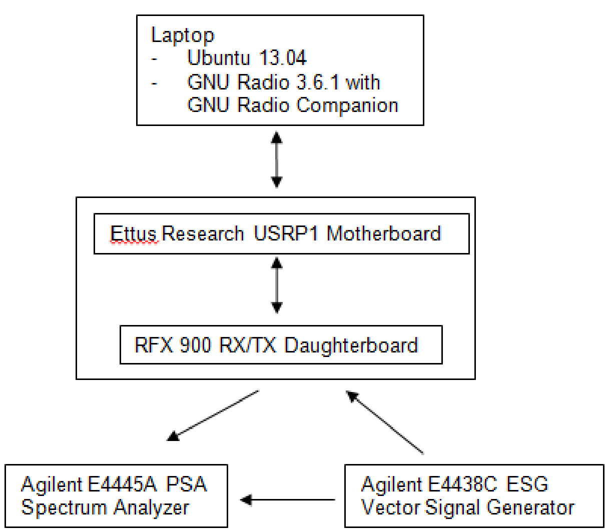

Fig. 4. Block diagram of experimental setup

interference avoidance algorithms, a similar band selection algorithm was implemented in a separate previous test bed developed at Stevens Institute of Technology [4]. Each of these algorithms were written for an older version of GNU Radio and then adapted for a more current version of the software. Fig. 5 is a screenshot of the GNU Radio Companion software.

B. *Universal Software Radio Periphery*

The Universal Software Radio Periphery, or USRP, is the hardware RF front end of a software-defined radio system. The USRP used in this project was the Ettus Research USRP1. The motherboard on this model contains four daughterboard ports.

The daughterboard used was the Ettus Research RFX 900 RX/TX. This has transceiver capabilities with a center frequency at 900 MHz and a bandwidth of 200 MHz. The GNU Radio application written divides this bandwidth into five bands of 40 MHz each. The daughterboard has two antenna ports: one for transmission and one for reception. Fig. 6 depicts the USRP1 with an RFX 900 with two antennas.

C. *Instruments*

An Agilent E4438C ESG Vector Signal Generator was used to simulate signals from primary users. Additionally, an Agilent E4445A PSA Spectrum Analyzer was used to monitor signals sent from both the signal generator and the USRP. Fig. 7 depicts the signal generator and Fig. 8 depicts the spectrum analyzer.

V. Results and Observations

Three experiments were run to test the programs. The first experiment was designed to determine the USRP's band selection preference. The second experiment tested whether the USRP could detect outside signals upon startup. The third experiment was designed to test if the USRP could successfully yield to a priority user.

A. *Experiment 1: Band Selection*

The purpose of Experiment 1 was to determine the USRP's preference of band after the initial spectrum scan. The program was run several times and the band chosen by the USRP was recorded. The signal generator was not used for this experiment. The results of Experiment 1 are shown in Fig. 9.

B. *Experiment 2: Signal Detection*

The purpose of Experiment 2 was to test the ability of the URSP to detect a signal. The signal generator was used to send a signal through a random frequency within a specified band and the program was run several times. If the USRP chose the occupied band after the initial scan, this was considered a failure. If the USRP chose a different band, this was considered a success. The result of each scan was recorded and the success rate was then calculated. This experiment was repeated with signal strength and frequency band of the signal generator as variables. The results of Experiment 2 are shown in Fig. 10.

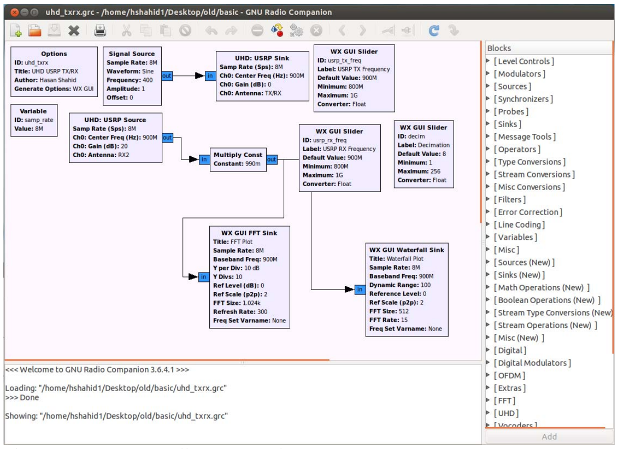

Fig. 5. GNU Radio Companion.

Fig. 6. Ettus Research USRP1 with RFX 900 TX/RX.

Fig. 7. Agilent Signal Generator.

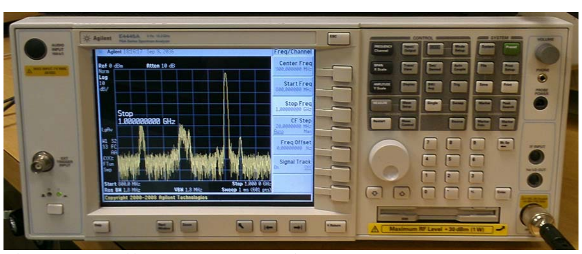

Fig 8. Agilent Spectrum Analyzer.

C. *Experiment 3: Interference Avoidance*

The purpose of Experiment 3 was to test the ability of the USRP to yield to a priority user. Once the program was run and the USRP was transmitting a signal within the chosen band, the signal generator was used to send a signal within this band. The USRP would then detect the signal, rescan the spectrum, and select another transmission band. If the USRP chose the occupied band, this was considered a failure. If the USRP chose a different band, this was considered a success. The result of each successive scan was recorded and the success rate was then calculated. This experiment was repeated with signal strength of the signal generator as a variable. The results of Experiment 3 are shown in Fig. 11.

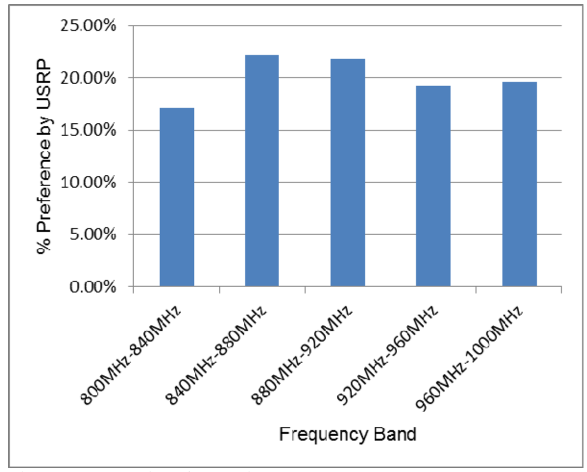

Fig. 9. Results of Experiment 1

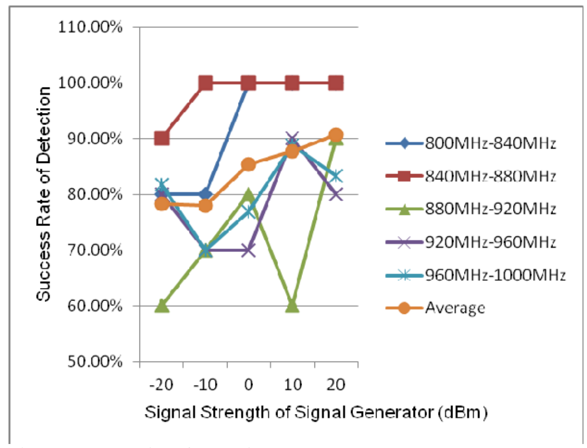

Fig. 10. Results of Experiment 2

D. *Observations*

While the developed test bed and program were successful, there were some hardware issues. The channel selection algorithm was not entirely accurate as transmission from the USRP interfered with the spectrum scan [4]. Additionally, the distance between a transmitter antenna and a receiver antenna significantly affected the measured signal strength. For this reason, the USRP had to be extremely close to the signal generator to detect outside signals. Even when the USRP and the signal generator were in close vicinity, the USRP still did not detect the signal generator occasionally.

Certain pieces of equipment produced unwanted signals which the USRP would confuse with signals from the signal generator. At certain frequencies, the signal from the signal generator produced several harmonics, about 80 MHz apart. Additionally, there was a spike in noise from the industrial, scientific, and medical (ISM) band between 902 MHz and 928 MHz.

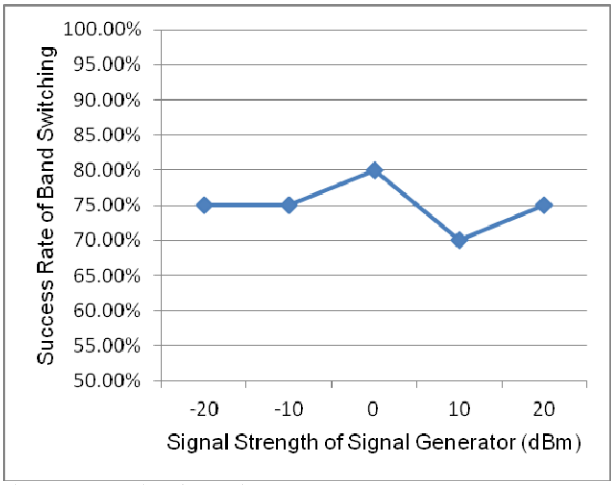

Fig. 11. Results of Experiment 3

VI. Conclusions and Further Work

The test bed and programs were largely successful. The programs successfully defined an ideal bandwidth for transmission. The preference of operating band of the USRP was even across the usable spectrum. The program also scanned this bandwidth for outside signals. The average success rate of occupied channel detection at startup ranged from about 78% for outside signals at -20 dBm to about 91% for outside signals at 20 dBm. If other signals were detected, the USRP yielded to these signals and changed its transmission frequency to an unoccupied band. The average success rate of yielding to priority users was about 75% at all power levels for outside signals.

Despite the success of the project, further work is needed. Hardware limitations hindered the operation of the program. Transmission from the USRP interfered with the spectrum scan. Also, the low transmission and reception power of the USRP occasionally prevented the cognitive radio from detecting interference. The hardware should be adjusted to account for these issues.

While the program developed treats the USRP as a secondary user, it can be upgraded so that it can act as a priority user as well. For example, upon running the program, the USRP will act as the priority user in the chosen band. If an outside signal is detected, the source of this signal will be treated as a secondary user and the USRP will send a message to this device forcing it to leave the band. However, if the initial spectrum scan is unsuccessful and the USRP chooses an occupied band, the priority user in this band will send a message to the USRP forcing it to leave the band.

Additionally, the channel selection algorithm can be modified from a narrowband sensing scheme to a wideband sensing scheme. This transition would result in a more efficient channel selection process. This can be done in one of two ways: multiband joint detection or compressive sensing. Multiband joint detection entails scanning multiple bands simultaneously [5]. Compressive sensing involves sampling the spectrum and reconstructing the result to locate empty channels [6].

Acknowledgment

This project was made possible by Stevens Institute of Technology, the National Science Foundation, and the faculty and staff of the Stevens Electrical and Computer Engineering Department and of the Wireless Information Systems Engineering Laboratory (WISELAB).

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