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Research Article

Experimental Analysis Using USRP for Novel Wavelet-Based Spectrum Sensing for 2.2 GHZ Band Communication Using LabVIEW

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Spectrum sensing allows cognitive radio systems to detect relevant signals even in the presence of interference for reliable communication. Most of the existing spectrum sensing techniques use a particular signal-to-noise ratio model with assumptions and provide certain detection performance. Dynamic spectrum management techniques enabled the efficient allocation of channels to increasing number of users. In cognitive radio system, the dynamic spectrum management is efficient for sensing the channel occupancy and mobilizing the secondary user towards the unused primary user channel. For spectrum sensing, wavelet-based spectrum sensing method is analyzed and effectively made spectrum decision. The performance analysis is made for various SNR values with enhanced false alarm and throughput in spectrum management cognitive radio system in 2.2 GHZ band communication.

1. Introduction

The wireless communication technology has rapid advancement in 5G and increases high scarce in spectrum resources [1]. The overall spectrum usage is calculated with a variation of 7-34%, which clearly explains that the spectrum is utilized very minimum of availability [2]. The reusing of temporarily unoccupied spectrum holes provided that the licensed user is not affected with any interference [3]. Every band of spectrum has different characteristics for a number of users and frequency range. The unused spectrum is detected by the spectrum sensing method by which the secondary user has the ability to select based on availability and data security as required. The parameters such as path loss, interference, wireless link, and delays are all determined. Efficient spectrum utilization is a significant challenge in managing a multifaceted communication system. With multiple users with conflicting objectives sharing a common spectrum, some of whom may be hostile, prudent resource allocation is critical for effective frequency utilization [4]. The Federal Communications Commission (FCC) recently approved the use of an unlicensed device in the licensed band to address spectrum scarcity and inefficiency [5], which has sparked a lot of interest in this field of study. Cognitive radio, a software-defined radio (SDR) that can be reconfigured and reprogrammed, is one of the key enabling technologies to achieve this goal. The use of software processing to implement the radio system's operations is referred to as software-defined [6].

As part of the cognitive radio network (CRN), users must not only identify opportunities in the primary network but also ensure that those opportunities do not adversely affect the licensed network's users. It is necessary to have additional spectrum handover or mobility functionality in this case because the primary user appears on the channel currently being used by the CRN user. Spectrum handover has been accomplished using a wide variety of methods, including bioinspired [7], Markov [8], and supervised machine learning [9] techniques. CR is one of the most effective techniques for ensuring fair and flexible frequency allocation in various wireless communication technologies [10, 11]. There has been an increase in the use of wireless communication learning techniques [12, 13]. Due to the rapid advancements in technology, SS must be continuously improved. Several issues arise in this context, such as the need for large amounts of frequency resources, spatial availability sensing, spectrum intelligence sensing, and energy-efficient protocol design. There is improved spectrum efficiency in wavelet-based spectrum sensing where the SUs use the spectrum without interfering with the PUs. Molina-Tenorio et al. [14] tried to come up with a new way to sense the multiband spectrum. This method is used in cognitive radios. Multiresolution analysis (wavelets), machine learning, and the Higuchi fractal dimension are the foundations of this method. Using this method, it is planned to connect several inexpensive software-defined radios so that they can sense a wide band of the radio electric spectrum. This work showed that the impulse noise elimination module did a good job of getting rid of high-frequency noise and sudden changes in the signal. The MBSS technique that was put into place worked well, with the same results as the simulations (0.98 of PS and two (mean) wrong samples when trying to find the PU transmission). Still, this device's performance could be better if it had a higher-gain antenna and if the SDR deployment was done in parallel, which would cut down on execution time and make better use of computing resources. The effective implementation of CR on GNU radio using an energy-based spectrum sensing method for real-time video transmission as a primary user was performed by Patil et al. [15]. The proposed system can indicate the frequency band occupancy by setting the detection output, according to the evaluation results. With the start of video transmission, the detection output changes to one. The goal of this project is to develop a spectrum sensing method that is best suited for detecting white spaces in video transmission as a primary user on the SDR platform [15]. The SDR is a wireless communications emerging technology that can be used with USRP and the GNU radio platform to implement cognitive radio detection. The results obtained in real time are proof-of-concept for the test bed that was constructed. Furthermore, the disparity in performance between the energy sensor simulations and test bed results highlights the hardware limitations [16]. Brodersen et al. [17] studied novel filter bank-based cooperative spectrum sensing. The study demonstrates that AFB-based CSS with FBMC waveform can significantly enhance performance. The second case study examines a novel CSS based on a maximum–minimum energy detector (Max–Min ED). It is anticipated that the proposed method will effectively address the issue of noise uncertainty (NU) with significantly less implementation complexity than existing methods. The developed algorithm with reduced complexity, improved detection performance, and improved reliability is presented as an attractive solution to counteract the practical effects of a wireless channel with low SNR. Probability expressions in closed form are derived for the threshold, false alarm, and detection probabilities when frequency selective scenarios are considered under NU. The validity of the novel expressions is demonstrated by comparing them to respective simulation results.

2. Cognitive Radio

Spectrum management consists of allocating the specific frequency band to a specific secondary user shown in Figure 1. This allocation of spectrum depends on primary user activity and spectrum availability. If primary user behavior cannot be predicted for a certain band over a particular time period, then the cognitive radio system switches the secondary user to another band where the primary user behavior is fixed partially. The most suitable frequency band selection is the main criteria in spectrum management. Spectrum sharing needs other users coordination in the spectrum range except for malicious user if present in the system. It represents that the spectrum is an unoccupied band and is trying to collect the secondary user data. Spectrum mobility and its effective handover provides the uninterrupted communication for dynamic spectrum access. The spectrum holes are the unused spaces of the spectrum. If primary user becomes active, then the spectrum mobility is interrupted with the communication. The spectrum holes are the unused or underutilized spaces present in the spectrum. This system provides high data rate, long range, coverage, and less interference and operated in licensed and unlicensed band.

3. Spectrum Sensing Detection Method

Spectrum sensing is one of the most required detection processes implemented in cognitive radio systems. Cognitive radio systems allow the secondary users to learn the radio environment for detecting the primary user signal's presence by applying several methods and take decision for further transmission in the specified band. Figure 2 represents the spectrum sensing model.

The seamless spectrum sensing for a wide spectrum band provides the flexibility with respect to configurations as in [19] executing the parallel processing based on processing time. After detection of the available spectrum holes, the transmission terms of cognitive radio system are spectrum holes and power levels. To provide the dynamic spectrum management, the secondary users of the empty bands are required to align with primary users and interference temperature at the receiver should not exceed the limit [20]. The radio spectrum is periodically monitored by cognitive radio system and detected the presence of spectrum holes. When primary users (PUs) are active, then the secondary users in the same frequency band are not active. When the communication among SUs is active, then primary users want to transmit in the same frequency band. Hence, the secondary user is required to leave the band for specified time period in order to avoid interference. The transmitter power control needs to be adaptive as in [21].

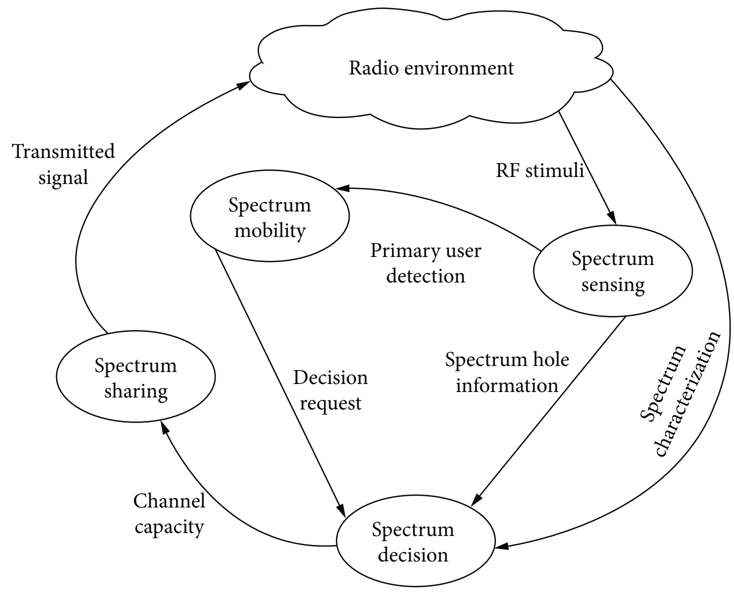


FIGURE 1: Spectrum management [18].

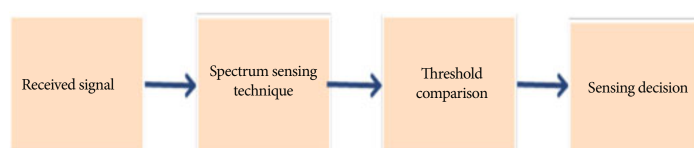


FIGURE 2: Spectrum sensing model.

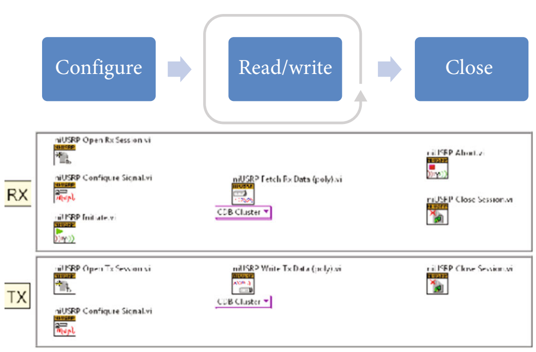


FIGURE 3: USRP transmit and receive functions.

4. Universal Software Radio Peripheral (USRP)

In comparison to current technologies that use radar to detect movement, programmable USRP radios are lighter and less expensive, and they can be programmed to send a signal through a wall and receive the reflection as it bounces off an object on the other side. Furthermore, USRP devices have the advantage of being programmable and operating in the license-free Industry, Scientific, and Medical (ISM) bands of 2.4–2.5 GHz and 4.9–5.85 GHz [22]. I/Q data is modulated and successfully handled by the USRP transmit and receive functions. The transmitter and receiver is configured to transmit and receive the I/Q data. Transmit functions include open, configure, write, and close the session. Receive functions include open, configure, initiate, fetch the data, and close the session. Figure 3 shows the transmit and receive functions. The transmitter and receivers specifications of USRP are given in Table 1 and Table 2, respectively.

5. Proposed Wavelet-Based Spectrum Sensing Approach

The wavelet-based detection technique differs from other techniques in that it works in both the frequency and time domains, whereas other techniques only work in the frequency domain [23]. Because of its time-frequency characteristics, a wavelet is unique in that it can localize a signal in terms of frequency and time using its scaling and wavelet functions. For spectrum sensing, wavelets are implemented using filter banks with highly desirable properties [24]. The frequency bands of interest are commonly decomposed into a sequence of consecutive frequency subbands by applying wavelet-based spectrum sensing method. Wavelet-based detection method provides advantage in spectrum detection with simplicity and methods in terms of both simplicity and flexibility. This approach can be used to identify the spectrum holes in the radio resources for dynamic spectrum access. Consider the spectrum as the sequence of frequency subbands. Every subband has smooth power characteristics within the subband range but varies abruptly on the edge of the successive subband. With the use of the wavelet

Table 1: USRP2920 transmitter specifications.

Specifications	Range
Frequency range	50 MHz to 2.2 GHz
Maximum output power (P_{out})	50 MHz to 1.2 GHz -50 mW to 100 mW 1.2 GHz to 2.2 GHz -30 mW to 70 mW
Gain range	0 dB to 31 dB

Table 2: USRP 2920 receiver specifications.

Specifications	Range
Frequency range	50 MHz to 2.2 GHz
Frequency step	<1 kHz
Gain range	0 dB to 31 dB

detection technique, the spectrum spaces may be observed in a given time instant by finding the obtained result. The energy of the reception signal is calculated to detect the presence of the primary user. From the detected spectrum, the primary user is present when a calculated energy level is greater than the threshold energy level. It also compares the output of the energy detector with a threshold that depends on the noise level and the signal is detected. Energy detection technique does not require prior knowledge of the primary user. But the details are required by matched filter, so it has relatively less complexity than other spectrum detection techniques [25]. $y(n)$ is equal to the sampled signal to be analyzed and $x(n)$ is equal to the input signal.

Primary user presence is confirmed when the energy of the signal is greater than the threshold.

Primary user absence is confirmed when the energy of the signal is lesser than the threshold.

Let$y$be considered the signal received which is represented in Figure 4.

If the spectrum energy level is found to be free which is detected by the secondary users, then communication will continue between secondary users. Spectrum monitoring is done periodically. After, certain iterations in the loop structure given in the following diagram provide the spectrum monitoring operation.

The power spectral density values for wavelet transformed signal are used to calculate edge. The block diagram of transmitter and receiver implemented in LabVIEW is shown in Figures 5(a) and 5(b). The edge is compared with sensing threshold λ. The sensing decision is expressed as follows:

(i) If $e \geq \lambda$, PU signal absent

(ii) If $e < \lambda$, PU signal present

The wavelet edge is considered for sensing decisions since one spike of the signal represents the power density of a given signal frequency, while multiple spikes represent the addition of noise. The power density function of noiseless signal and noisy signal is shown in Figures 6(a) and 6(b).

Spectrum sensing technique is arrived with edge detection in turn represents spectrum whole detection. The performance analysis is simulated for the wavelet transform energy detection and the conventional energy detection while the evaluation of the system was performed using the signal-to-noise ratio (SNR).

6. Simulation Results and Analysis

The simulation is done for transmitter section and receiver section. The transmitter section consists of generating the signal frequency and wavelet transformation of the samples is further calculated for power spectral density. The energy values calculated are used to determine the spectrum detection. The received signal is a complex signal; power spectral density is calculated on a linear scale of the frequency. The power spectra are calculated, estimating the periodogram. The IQ samples rate is considered 200 k and gain of value 10. The front panel design of transmitter with specifications is depicted in Figures 7(a) and 7(b). The coerced gain frequency is considered 500MHZ, USRP 2920 IP address is mentioned as 192.168.10.3

If no channel is selected by a secondary user within the band, then no common channel will be opted. Figure 8 represents the front panel of the USRP test bed. The detection of the signal for the carrier frequency of 1.4GHZ is detected and PSD will be calculated periodically. The detection of the signal for the carrier frequency of 1.4GHZ. False alarm probability is 0.01 kept for analysis. Smoothing factor is considered L with value 10, and then, probability of false alarm is represented by Pfa as 0.01. It gets compared with upper and lower thresholds. Table 3 shows the wavelet detection for trail 1 and trail 2. It exceeds the threshold. Hence, green light represents the primary user presence when primary user transmits the signal in the given frequency ranges. The experimental setup for USRP transmitter and receiver is shown in Figure 9.

Radio spectrum comprises of electromagnetic frequencies ranging lower than 30 GHz or having wavelength larger than 1 millimeter (mm). Various parts of the radio spectrum are allocated for different kinds of communication application varying from microphones to satellite communication. The IP address for USRP is 192.168.10.3, which makes the host to work as Host PC which is assigned an IP address in the same subnet. GUI application developed produces the FFT of the received signal. The designed application works as a broad band receiver; it fetches the signal from the external source environment and output as I and Q data into the appended file. After passing through USRP, the raw data bit streams are converted to arrays. FFT is performed

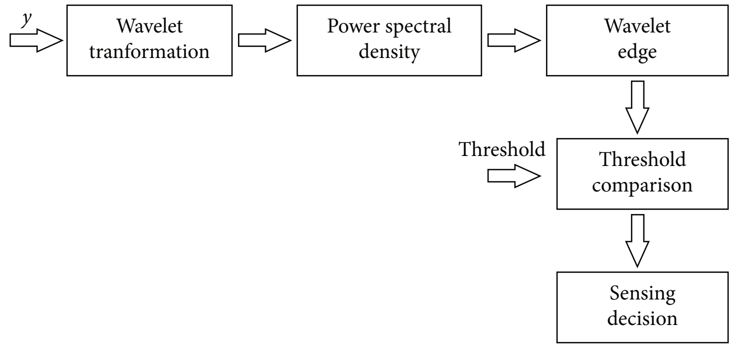
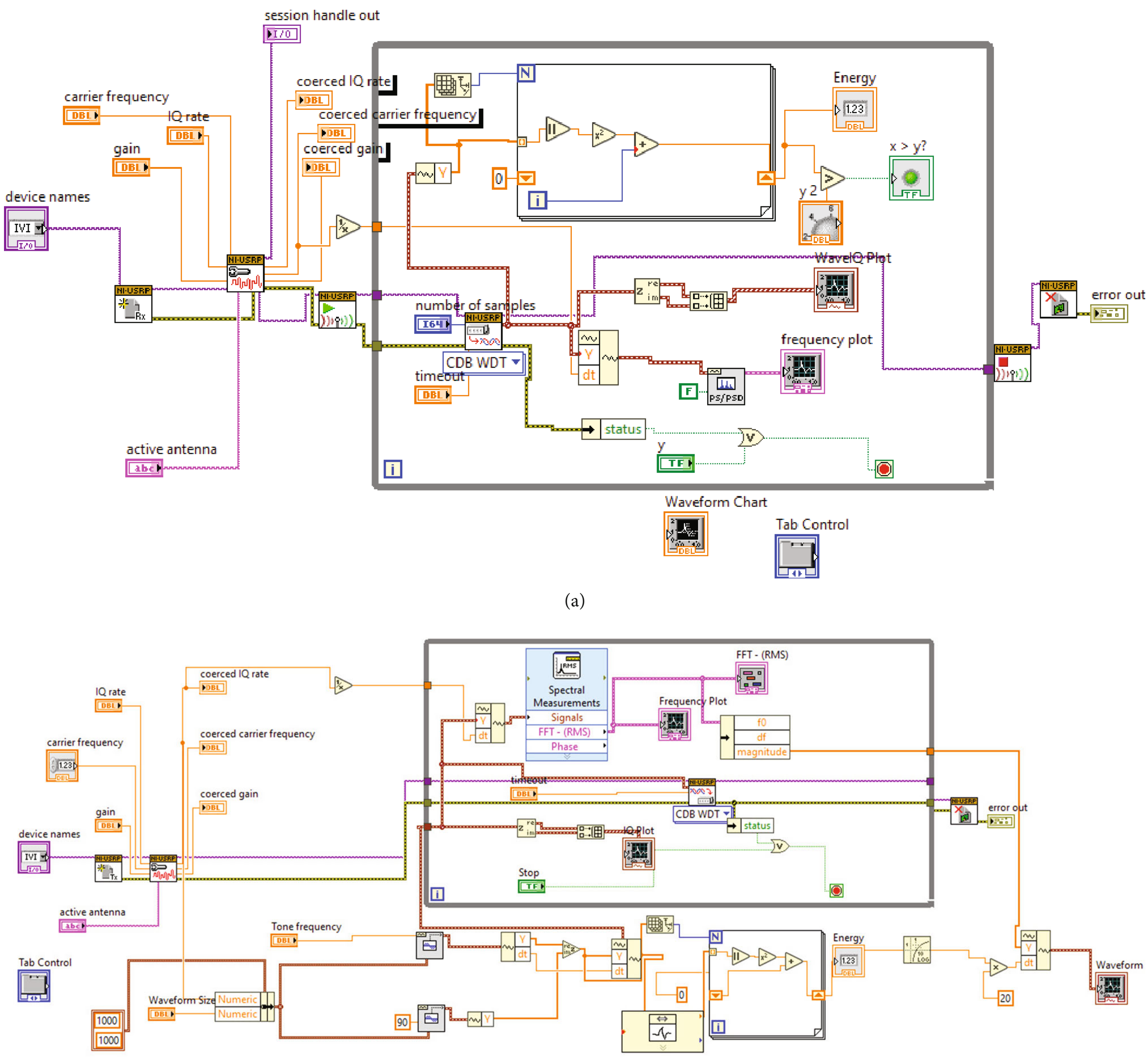


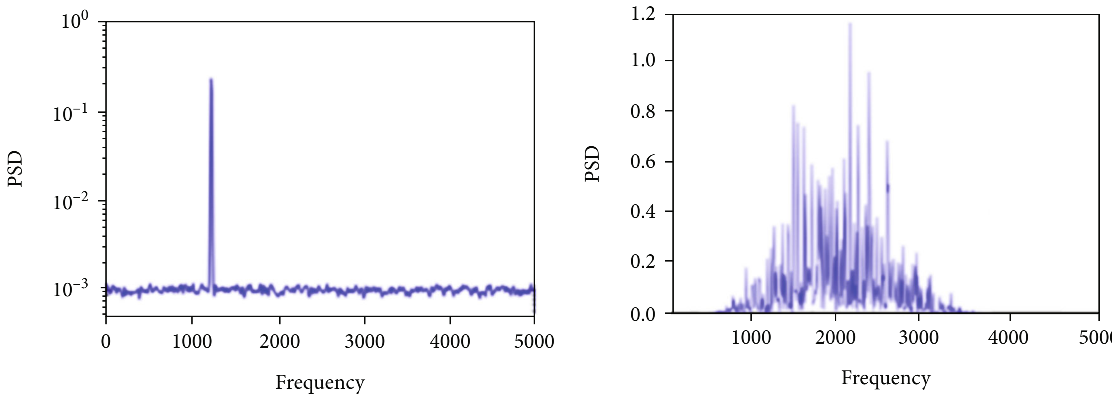
Figure 4: Wavelet-based sensing system model.



(a)

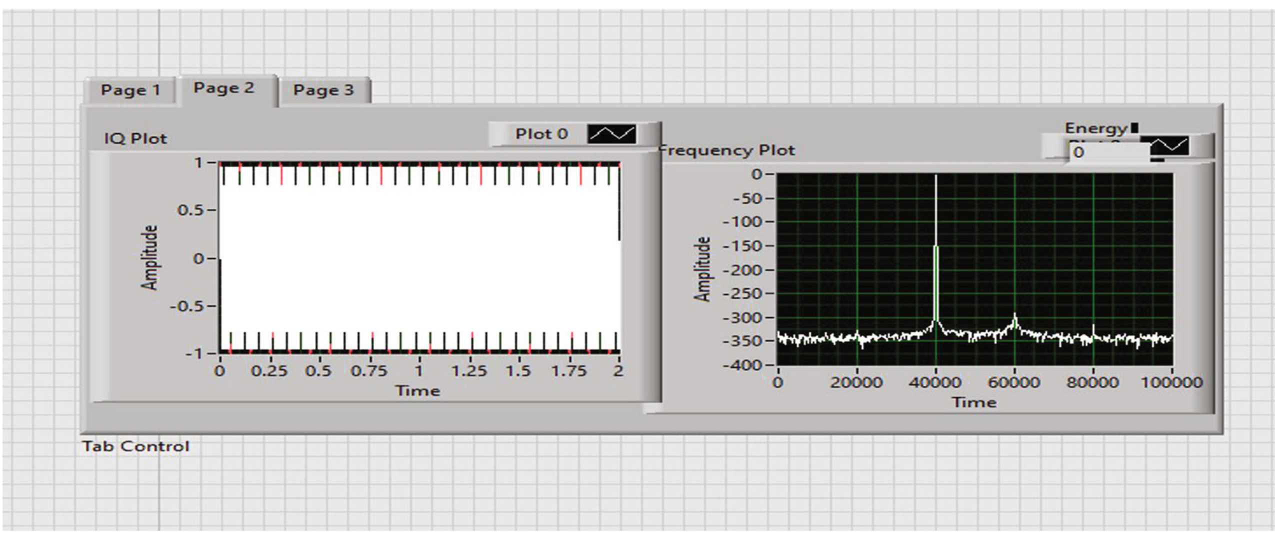
(b)

Figure 5: (a) Block diagram of baseband receiver. (b) Block diagram of baseband transmitter.

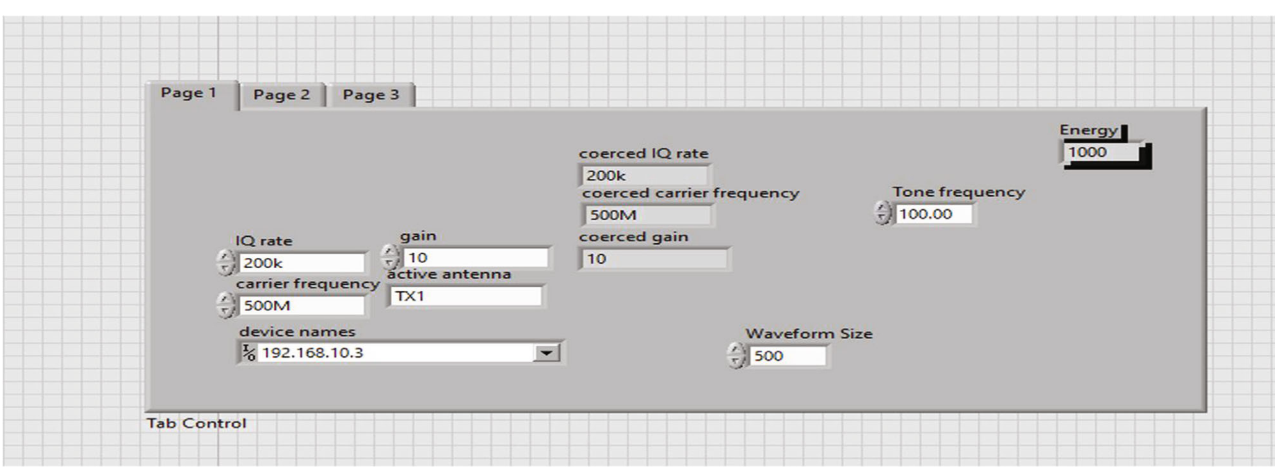


(a) (b)

Figure 6: Power density function of (a) noiseless signal and (b) noisy signal.



(a)



(b)

Figure 7: (a and b) Front panel design of transmitter with specifications.

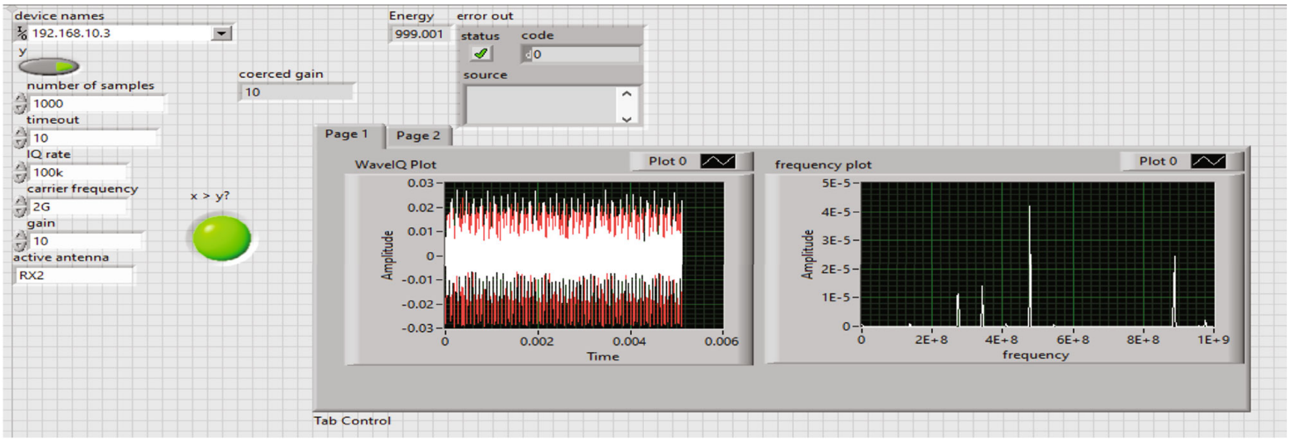


Figure 8: Front panel design for spectrum sensing by secondary users.

Table 3: Wavelet detection.

Trail	Energy	Threshold for $P_{fa} = 0.01$	Decision
1	10.225	4.0526	Signal exist
2	3.263	4.0526	Signal does not exist

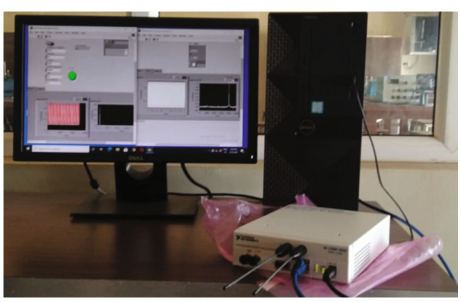


Figure 9: Experimental setup for USRP transmitter and receiver for spectrum detection.

with the help of signal processing blocks and it is passed through the Blackman-Harris window to overcome the spectral leakage effect.

7. Implementation

USRP 2920 can communicate the signal within the range of 50 MHz to 2.2 GHz, hence implanting the test bed under this frequency. The IQ samples are transmitted with the sampling rate of 200 k and carrier frequency considered 2 GHz with gain values as 10 and waveform sizes are taken as 300. The data values are fetched from the USRP fetch block in receive mode. The energy values are calculated and the energy detection procedure is applied to the data values.

The test bed is implemented for and verified the energy detection as shown in Figure 9.

$$\text{No.of FFT Frames} = \frac{(\text{Decimation Rate} * \text{Time delay})}{\text{FFT window size}} \quad (1)$$

8. Conclusion

The sensing technique is proposed to implement a spectrum management system for the process of spectrum sensing at 50 MHZ to 2.2 GHZ frequencies using USRP. The peak power is observed around the frequency ranges. The spectrum detection method was identified in AWGN noise environment and does not depend on the channel and transmitter characteristics. The proposed cognitive radio method is used for efficient spectrum utilization even in low SNR regions. The dynamic spectrum management used to detect the spectrum enabled the efficient allocation of channels to increasing number of users. The performance analysis is proved for various SNR values with enhanced false alarm and throughput in spectrum management cognitive radio system in the given operated frequency band communication.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication.

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