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Analysis of radio frequency spectrum usage using cognitive radio

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ABSTRACT

This paper presents the analysis of radio frequency (RF) spectrum usage using cognitive radio. The aim was to determine the unused spectrum frequency bands for efficiently utilization. A program was written to reuse a range of vacant frequency with different model element working together to produce a spectrum sensing in MATLAB/Simulink environment. The developed Simulink model was interfaced with a register transfer level - software defined radio, which measures the estimated noise power of the received signal over a given time and bandwidth. The threshold estimation performed generates a 1\0 output for decision and prediction. It was observed that some spectrum, identified as vacant frequency, were underutilized in FM station in Benin City. The result showed that when cognitive radio displays "1" output, which is decision H_1, the channel is occupied and cannot be used by the cognitive radio for communication. Conversely, when "0" output (decision H_0) is displayed, the channel is unoccupied. There is a gradual decrease in the probability of detection (P_d), when the probability of false alarm (P_{fa}) is increased from 1% to 5%. In the presence of higher P_{fa}, the P_d of the receiver maintains a high stability. Hence, the analysis finds the spectrum hole and identifies how it can be reused.

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1. Introduction

The demand for the radio frequency (RF) spectrum is rising due to the development of new devices and services [1]. The evolving communication technologies require the use of the RF spectrum for their functionality. This brings problems such as communication field spectrum scarcity since each application requires spectrum to operate [2]. A major reasons for the dearth spectrum is due to inefficient utilization of the accessible spectrum [3]. The primary tool of spectrum management is a licensing system through bidding by allotting blocks of spectrum with assigned licenses for specialized usage to specific users or companies. The RF spectrum has different bandwidths assigned to different communication bodies, which make use of the

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spectrum. These assigned bandwidths are fixed to the respective bodies. However the RF spectrum, which spans from 8.3 kHz to 300GHz seems occupied as it has been apportioned into blocks and with assigned licenses to specific users by the Nigerian Communication Commission. Most companies do not fully use the spectrum assigned to them. The uneconomical use of the accessible spectrum has led to a situation where new applications are contending for free spectrum for usage. This inefficient utilization results in artificial scarcity of the spectrum. In spite of the fact that the spectrum is not enough, low income company cannot buy to transmit signal [4]. Hence, there is a need for an efficient usage of the available spectrum in order to eliminate the problem of spectrum scarcity [5].

One of the solutions to spectrum scarcity is the identification of spectrum holes created when primary users are not utilizing the allotted spectrum at any given time. The cognitive radios technology can eliminate artificial spectrum scarcity due to its ability to use the spectrum for communication whether licensed or not licensed, so long it does not interfere with other licensed users. Several studies [6]–[10] have established the potential of cognitive radio for automatically detection of available channels in a wireless spectrum but usually ignore the monitoring and the utilization of spectrum holes without interference. The technology is conscious of its internal state and environment and can decide its radio operating behavior to realize the predefined objectives. In addition, it can coexist with primary users for exploiting the underutilized spectrum. Moreover, improved spectrum occupancy can be achieved by speculatively identifying and utilizing the available spectrum resources with no harmful interference [9]. The cognitive radio can be employed in distributed, network-centric, mesh and ad-hoc architectures as it can serve the needs of both licensed and unlicensed usage. The cognitive ability of this technique is a process of observing the outside environment with a view to determine unused radio spectrum with suitable communication parameters to adapt to the dynamic radio environment [11].

The overall aim of this paper is the monitoring of the spectrum usage and signal identification using cognitive radio. The specific objectives are to determine the unused spectrum frequency bands, efficiently utilize the unused spectrum frequency bands and set up a Simulink model that will evaluate channel occupancy and prediction for channel selection. The implementation can generate more income for the primary spectrum users and reduce the problem of spectrum scarcity.

2. Methodology

This study made use of spectrum sensing by means of a software defined radio known as register transfer level - software defined radio (RTL-SDR), SDR Sharp (#SDR) digital signal processing software, and antenna. The RTL-SDR receiver dongle is interfaced with the MATLAB/Simulink where the fundamental software operations are implemented to measure the estimated noise power of the received signal over a specified time duration and bandwidth and also perform threshold estimation and then generate a 1/0 decision for signal detection and prediction. The developed Simulink model for spectrum monitoring is shown in Fig. 1 while the frequency spectrum control plan is shown in Fig. 2. The selected centered frequency was set at 108MHz and the threshold gain at 35dB while the gain of filter which select the required frequency was set at 1dB and the spectrum analyzer uses fast Fourier transform (FFT) to display the analyzed signal in real time domain.

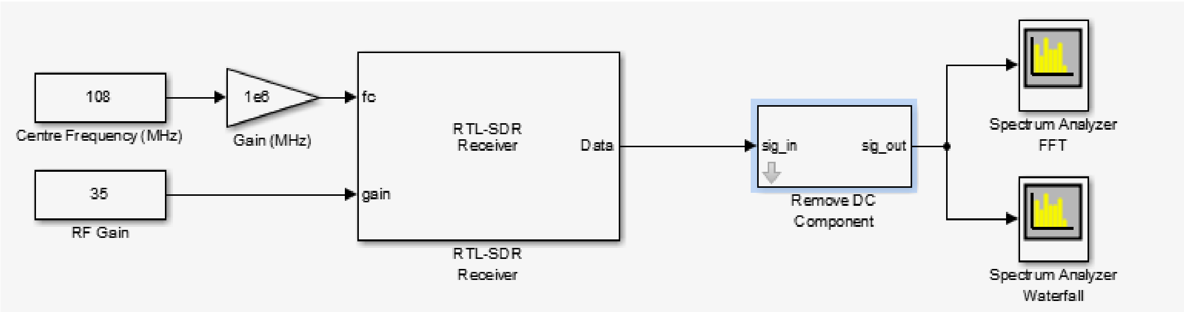

Fig. 1 Simulink model for spectrum monitoring

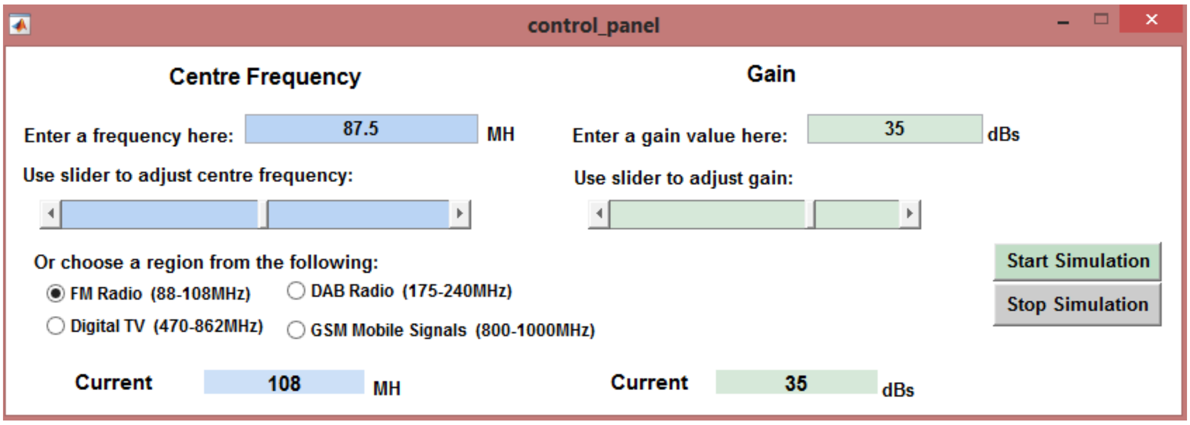

Fig. 2 Frequency spectrum control plan

2.1. SDR Sharp Software

The #SDR is a simple, intuitive and fast PC-based digital signal processing application for SDR, written typically in C#. The objective is to proffer an easy proof of concept application into digital signal processing (DSP) techniques. It can support the RTL-SDR and performs real time DSP and it has a graphical user interface (GUI) for viewing of signals in any frequency band that it is tuned to, depending on the receiving frequency range of the connected radio. In this paper, the #SDR is used to first confirm signals in the particular frequency band of interest and then the signal information such as the center frequency of the signal of interest is then used to tune the Simulink RTL-SDR receiver to that particular center frequency. The #SDR GUI has two major displays; the FFT display that shows the FFT of signals in the frequency domain and the Water Fall display, which shows a graphical representation of the signals across a frequency range generally color-coded (red color) to indicate signal amplitude or strength, displayed over time. The FM radio spectrum was monitor in Benin City to identify the unused (vacate) and used spectrum as shown in Fig. 3 while Fig. 4 shows the graphical users interface display illustrating the 95.75 MHz FM band.

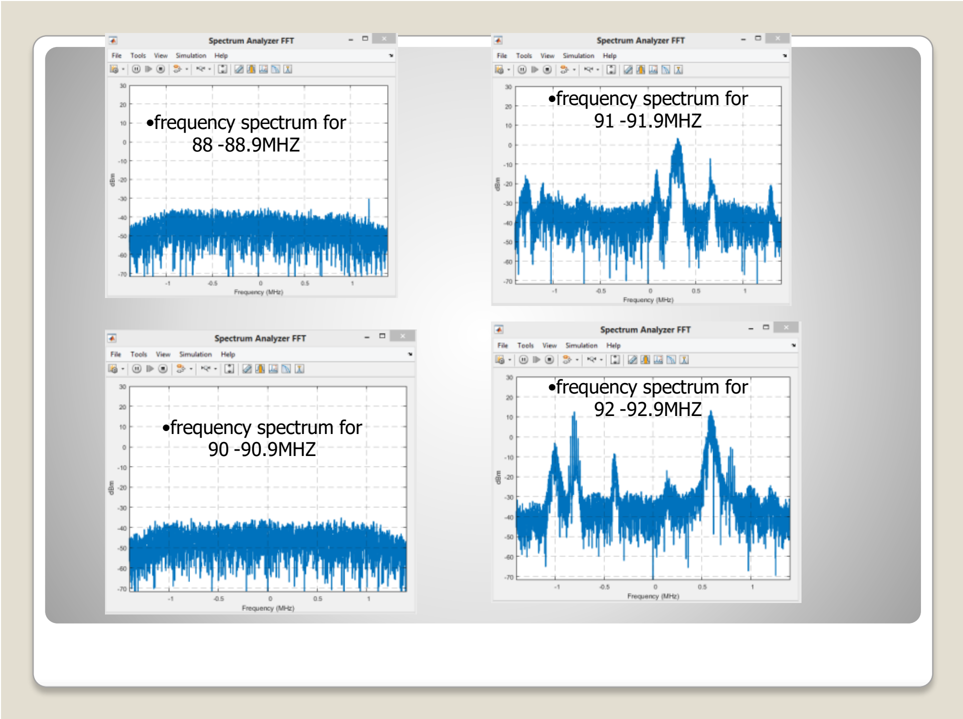

Fig. 3 Frequency spectrum of different frequency range.

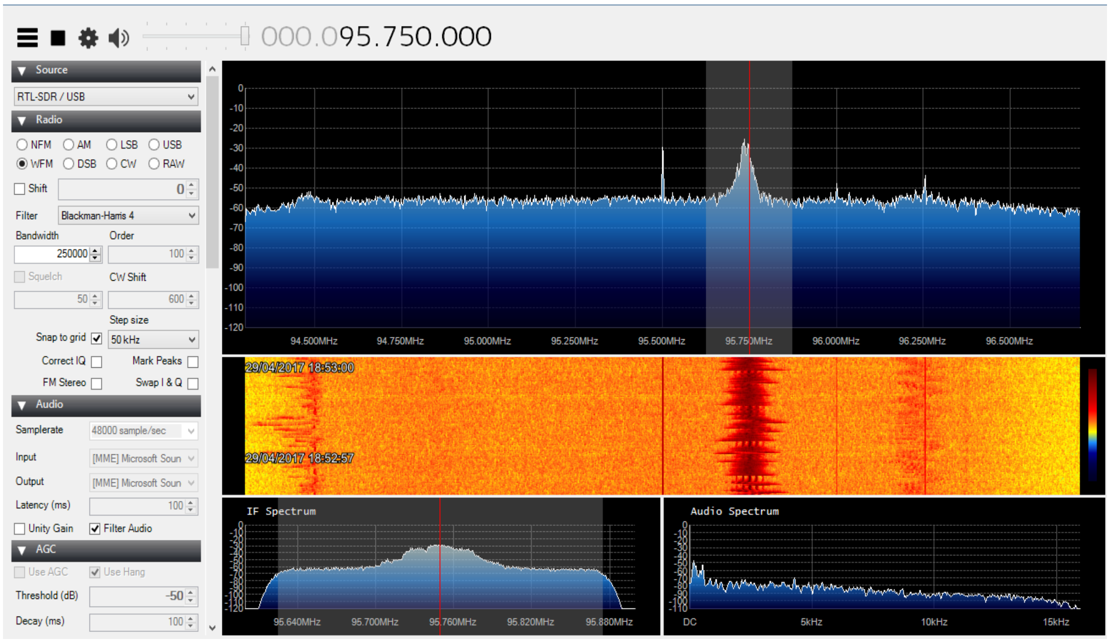

Fig. 4 The #SDR GUI showing the 95.750 MHz FM band

2.2. Modeling of the Spectrum Sensing Cognitive Radio

This study utilizes the architecture for non-cooperative spectrum sensing where an individual cognitive radio device or secondary user does the non-cooperative spectrum sensing process locally. Each secondary user sensed the spectrum channel to detect the absence or presence of a primary user. The proposed model for the spectrum sensing cognitive radio simulation setup is shown in Fig. 5

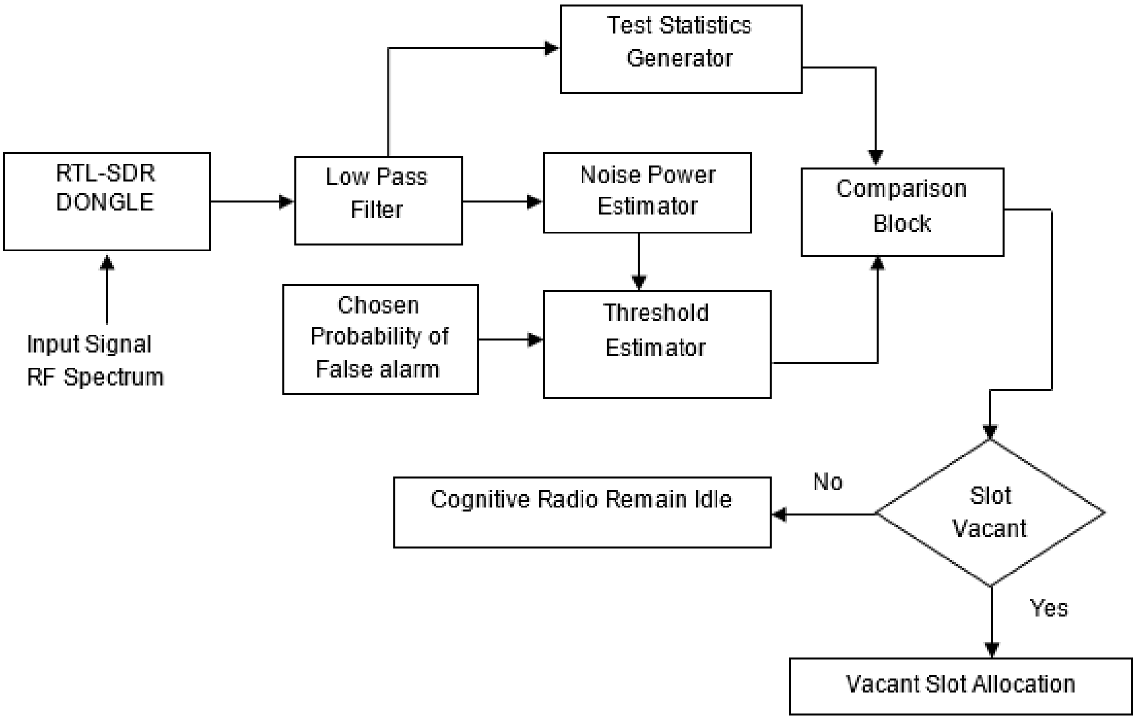

Fig. 5 Simulation model for spectrum sensing and signal identification cognitive radio

Testing the spectrum sensing cognitive radio in real time was done by evaluating the efficiency of the spectrum sensing RTL-SDR cognitive radio using MATLAB/Simulink 2017 as standalone sensor architecture with the hypothesis model for energy detection.

3. Results and Discussion

The real time test result of the developed Simulink model of Fig. 1 are shown in Table 1. It can be seen that when a primary signal was present in the particular channel or bandwidth the radio was tuned into, the cognitive radio displayed a “1” output and that is decision H_1 meaning the channel is occupied; hence, cannot be used by the cognitive radio for communication. In the channel were there was no presence of information signal but only noise, the cognitive radio displayed a “0” output and that is decision H_0, meaning the channel is unoccupied; hence, the cognitive radio can perform further spectrum management and the channel for communication. The spectrum allocated for the FM sectional spectrum view display of the bandwidth using SDR sharp with FFT center frequency set to 95.750 MHz is shown in Fig. 6. As the probability of false alarm (P_{fa}) increases from 1 – 5 %, there is a gradual decline in the probability of detection P_{fa} as it goes below 2%. Thus, when designing the energy detectors for spectrum sensing, P_{fa} as a design parameter should be kept minimal.

Table 1 Simulated result of Simulink model

Primary signal	Cognitive decision (H_o/H_1)	Status
94.5 MHz FM band	1	Primary signal present
95.00 MHz FM band	0	Primary signal absent, noise present
95.75 MHz FM band	1	Primary signal present

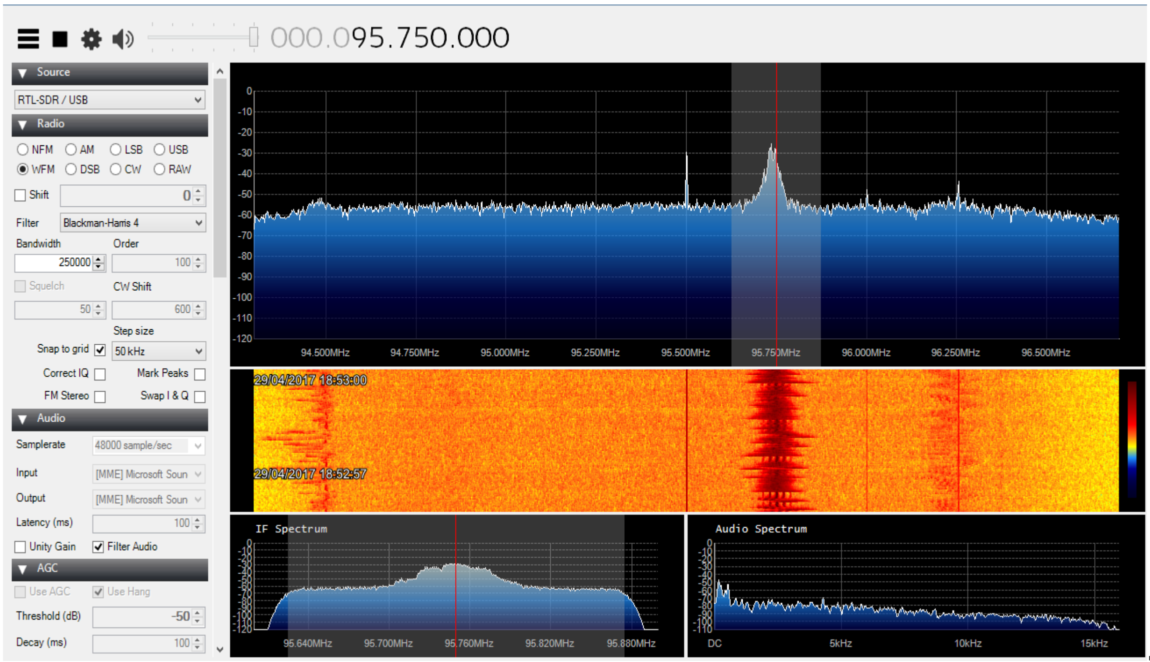

Fig. 6 Sectional spectrum view of the bandwidth allocation for FM using SDR sharp with FFT center frequency set to 95.75 MHz

Table 2 shows the spectrum sensing in the bandwidth allocated for FM (95.750MHz to 95.900MHz) with the center frequency set to 95.715210MHz.

Table 2 Spectrum sensing in the bandwidth allocated for FM (95.750MHz to 95.900MHz); center frequency set to 95.715210MHz.

Center Frequency (MHz)	Average Noise Power (W)	Threshold (%)	Probability of false alarm (P_{fa})	H_0/H_1
95.715210	0.007515	1	0.001859	0
		2	0.003719	0
		3	0.005578	0
		4	0.007438	0
		5	0.009297	0

The threshold for signal has been calculated by simulations, assuming only noise is received; that is, primary user is absent. But if only the noise energy lies above the threshold it corresponds to false alarm. This scenario was run for about 100 iterations and the result is the graph in Fig. 7. P_{fa} was calculated as energy above threshold divided by number of iteration. The graph shows that as the threshold is raised higher P_{fa} reduces. Hence a reasonable high threshold will reduce the probability of false alarm. Fig. 8 shows the probability of detection versus false alarm, which is a plot of the receiver operating characteristics. The curve shows that even in presence of higher the P_{fa}, the probability of detection of the receiver maintains a high stability.

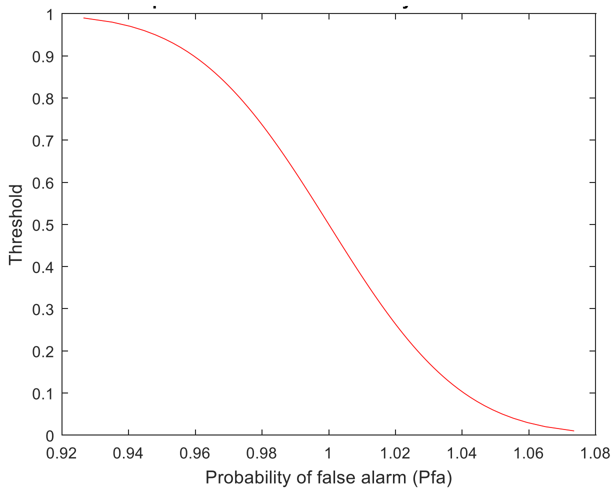

Fig. 7 Illustration of threshold versus probability of false alarm

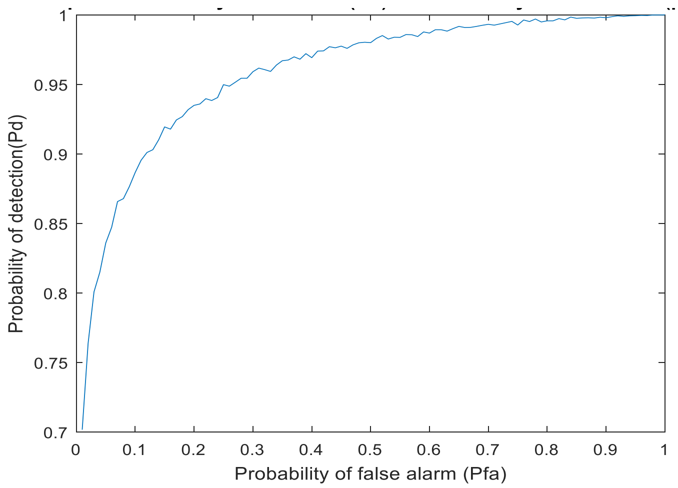

Fig. 8 Illustration of probability of detection versus P_{fa}

As observed (Fig. 7), when the P_{fa} is increased, the probability of detection decreases. Therefore, when choosing the probability of false alarm as a design parameter, it should be kept minimal to avoid false detections.

This paper can be extended to include an SDR transceiver to form a complete standalone cognitive radio, although the cost of implementing that is on the high side because getting an SDR transceiver can cost a few thousand dollars. The RTL-SDR is a low cost software defined radio hence the limitation of the tuner range, 25MHz to 1.5MHz is not sufficient enough to explore a larger part of the RF spectrum. There are other software defined radio whose tuner range far exceeds this range, such can be used to replace the RTL-SDR for wider sensing capability. There are software defined radios that have better sensing strength base on their filters, they can sense the slightest of signals in the midst of large amount of noise, and such can be used in the radio.

4. Conclusion

The aim was to determine the unused spectrum frequency bands for efficiently utilization. A program was written to reuse a range of vacant frequency with different model element working together to produce a spectrum sensing in MATLAB/Simulink environment. The developed Simulink model was interfaced with a register transfer level - software defined radio, which measures the estimated noise power of the received signal over a given time and bandwidth. The threshold estimation performed generates a 1\0 output for decision and prediction. The result showed an effective identification and monitoring of spectrum holes as it effectively utilize the unused spectrum frequency band without interference.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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