Monitoring of Spectrum Usage and Signal Identification Using Cognitive Radio

O. S. Omorogiuwa, E. J. Omozusi

Abstract**—**The monitoring of spectrum usage and signal identification, using cognitive radio, is done to identify frequencies that are vacant for reuse. It has been established that 'internet of things' device uses secondary frequency which is free, thereby facing the challenge of interference from other users, where some primary frequencies are not being utilised. The design was done by analysing a specific frequency spectrum, checking if all the frequency stations that range from 87.5-108 MHz are presently being used in Benin City, Edo State, Nigeria. From the results, it was noticed that by using Software Defined Radio/Simulink, we were able to identify vacant frequencies in the range of frequency under consideration. Also, we were able to use the significance of energy detection threshold to reuse this vacant frequency spectrum, when the cognitive radio displays a zero output (that is decision H0), meaning that the channel is unoccupied. Hence, the analysis was able to find the spectrum hole and identify how it can be reused.

Keywords**—**Spectrum, interference, telecommunication, cognitive radio, frequency.

I. INTRODUCTION

DUE to the continuous development of devices and services, our environment is transforming into spectrum demand, Radio Frequency (RF) spectrum has assigned various spectrum to various communication bodies that make use of the spectrum. The Nigerian Communications Commission (NCC) is responsible for radio spectrum regulation in Nigeria [1]; the primary tool of spectrum management by government is a licensing system through bidding. As we know spectrum is being apportioned into blocks for specific use [1]. These assigned spectrums are fixed to the respective bodies. Also with the continuous development of new discovery it brings the problems of spectrum shortage which poses as a major challenge of interference [2], [3]. Most intelligent applications need spectrum to function optimal but with the limited amount of spectrum available for the secondary users, cognitive radio is needed to eliminate the spectrum scarcity problem in both primary and secondary spectra. Major reasons for spectrum shortage are inefficient and ineffective utilization of the spectrum available. Spectrum is divided into two types of users; primary spectrum users (PSU) and secondary spectrum user (SSU), PS is a spectrum that is paid for, that means you need a license to use while SS is a spectrum that is free; you do not need a license [2]. One of the solutions in spectrum shortage is to identify the spectrum holes in the allotted frequency. Spectrum holes are identified when the license owners are not presently using the frequency while that of the secondary hole is created when the user device cannot see other devices using a particular frequency [2], [4].

Cognitive radio in itself is built upon the platform of Software Defined Radio (SDR). A SDR is a radio in which modulation, demodulation and filtering of signals can be performed on software regardless of the hardware part [4].

For cognitive radio to perform its task, it follows a procedure known as the cognitive circle. The cognitive circle is made up of four aspects: Spectrum Sensing; Decision; Sharing; and Mobility [5].

In this work, spectrum sensing will be exploited using a SDR known as the RTL-SDR (Register Transfer Level-SDR) and Spectrum Decision will be done by interfaced RTL-SDR with Simulink in which the basic software operations are performed.

In this work we based our research on FM (frequency modulation) radio stations which are the widely used in Nigeria. Table I shows a section of the National Frequency Table Allocation that will be relevant to this work. This table has been developed and periodically reviewed in conformity with the international regulations governing radio spectrum and the international/regional agreements signed by the Federal Republic of Nigeria in the capacity of the National Frequency Management Council. The predicted FM radio stations in Nigeria are shown in Table II; Fig. 1. From Table II, Fig. 1, it was noted that the FM station in some states is underutilized, and can be reused.

TABLE I
SECTION OF THE NATIONAL FREQUENCY ALLOCATION TABLE SHOWING FREQUENCY ALLOCATIONS BETWEEN FM [6]

Frequency Bands (MHz)	ITU Region 1 Allocations	Nigerian Allocations	Nigerian Utilization
87.5 - 100.0	Broadcasting	Broadcasting	Broadcasting (Fm radio)
100 - 108	Broadcasting	Broadcasting	Broadcasting (Fm radio)

II. METHODOLOGY

The predicted value of FM allocation, which is collected from NCC as shown in Table II, was compared with the frequency analyzer graph as shown in Figs. 6-9, to validate the result, to show if they are vacant and idle spectrum to be reuse, the result in Figs. 6-9 was seen using the designed Simulink interface in Figs. 4 and 5 working together to produce a spectrum sensing cognitive radio in MATLAB environment.

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TABLE II
ALLOCATED FM RADIO STATIONS IN SOME STATES IN NIGERIA [7]

STATE	ALLOCATED FM RADIO STATIONS							
ABUJA	87.9	88.9	92.1	92.9	93.5	94.7	95.1	96.1
	96.9	98.3	99.5	99.9	100.5	104.5	106.3	107.7
ABIA	88.1	93.3	94.9	101.9	102.9	103.5	103.9	104.1
ADAMAWA	91.1	95.7	101.5					
AKWA IBOM	90.5	100.7	101.1	104.5	104.9	105.9	107.5	
ANAMBRA	88.5	88.9	89.4	90.7	91.5	93.3	94.1	95.3
	95.7	99.1	102.5	103.5	106.5	90.1	107.1	
BAUCHI	94.6	98.5	95.7					
BAYELSA	94.7	95.5	97.1	102.5	106.5			
BENUE	89.9	95.0	96.5	99.9	103.5			
BORNO	90.7	94.5	95.3	99.5	102.5			
CROSS RIVER	92.6	95.9	99.5	104.5				
DELTA	88.6	89.9	93.1	95.1	96.1	97.9	98.7	100.5
	100.9	106.7	103.7	96.5				
EBONYI	98.1	101.5						
EDO	90.5	92.3	92.7	93.7	94.1	95.775	96.9	97.3
	100.1	101.5	105.5					
EKITI	91.5	100.5						
ENUGU	82.8	91.1	92.5	92.9	94.5	96.1	96.7	98.7
	100.9	106.5	106.9	107.2				
GOMBE	91.9	97.3						

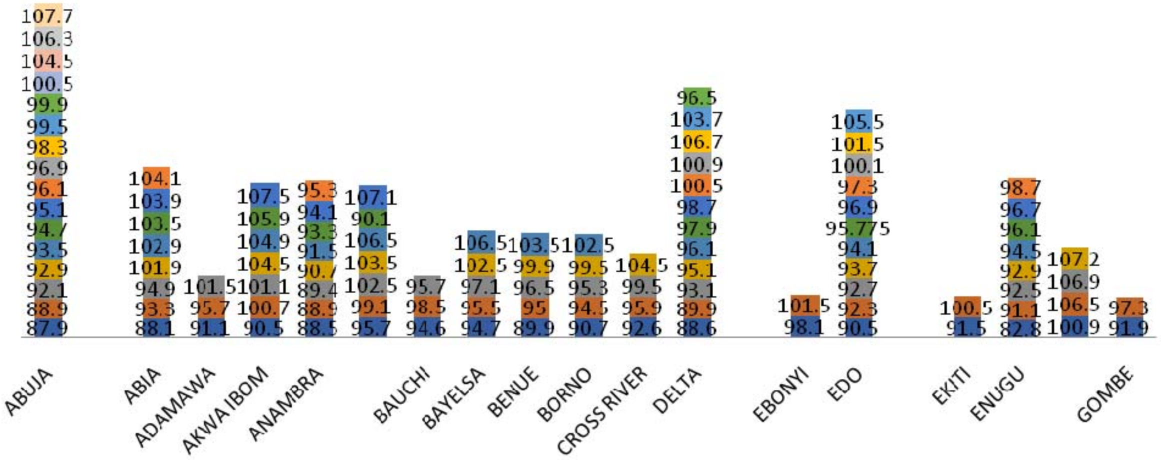


Fig. 1 The allocated frequency for some states in Nigeria

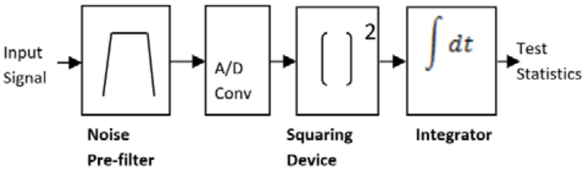


Fig. 2 Block diagram of the Energy Detector

A. The Spectrum Sensing Cognitive Radio

The cognitive radio system is divided into three modules, namely; spectrum sensing, spectrum predicting and spectrum management modules. This work focuses on the spectrum sensing aspect to predict the presence or absence of a signal. The energy detection method implemented with Simulink was used to achieve the spectrum sensing capability of the cognitive radio [8]. The Simulink tool of MATLAB for an OFDM system is used to simulate the energy detection feature. The block diagram depicted in Fig. 2 shows the system process of the energy detector.

The Energy Detector implemented was used to achieve the following:

i. Performing low noise pre filtration of received signal to limit noise and adjacent bandwidth signals.
ii. Sampling through the Analog to Digital (ADC) converter.
iii. Computation of covariance or magnitude squared of the energy signal to determine the power spectral density.
iv. Computing a test statistics from the computed power spectrum density which is then compared against a statistically generated threshold to ascertain the presence or absence of primary user signal.

B. Modelling of the Spectrum Sensing Cognitive Radio

This work 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. The spectrum channel detects the presence or absence of a primary user.

The system block diagram for the spectrum sensing cognitive radio/simulation setup and signal identification cognitive radio Simulink model is shown in Fig. 3.

The whole system in Fig. 3 can be divided into three major segments; the receiver segment, the energy detector/signal identification segment and the spectrum decision segment. The receiver segment and the energy detector/signal identification segment constitute the spectrum sensing and signal identification cognitive radio. The receiver segment consists of the RTL-SDR dongle, the energy detector segment consists of a low pass filter to allow the required set of frequencies of interest. Low signal is noted as noise, the threshold calculator has two constants fed into it as inputs. The two constants are the maximum noise power of a known frequency band gotten from the power estimator and a selected probability of false alarm. When signal is present that means it crossed through the threshold. An absence of primary signal is detected when the received energy goes below the limit set by the threshold and that means only noise is present that is H_o. Therefore that frequency slot is vacant for use by the cognitive radio for communication but if the received energy rises above the threshold set, it means primary signal present, that is H_1 and therefore the frequency slot is occupied and cannot be utilized by cognitive radio. Hence cognitive radio switches to another vacant slot if there is any idle.

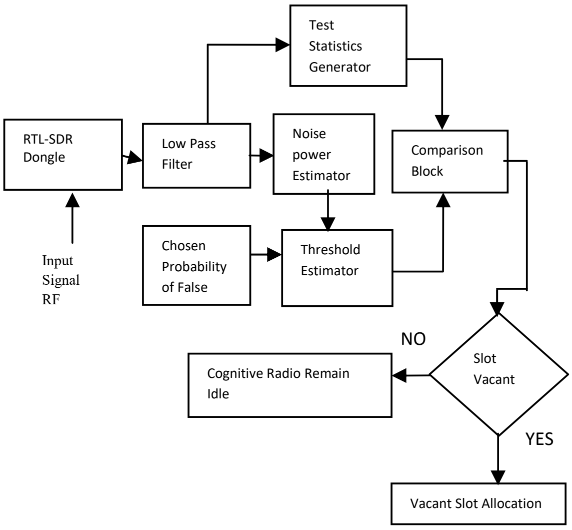
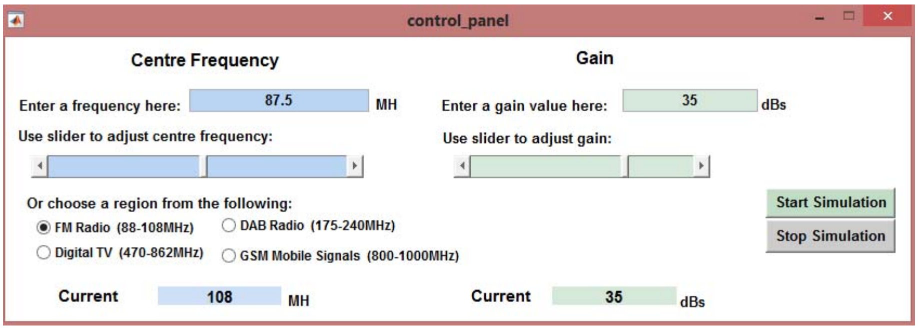


Fig. 3 Block diagram/Simulation set up of the Spectrum sensing and signal identification cognitive radio Simulink model

C. Working Parameters for the RTL-SDR Receiver

- Centre frequencies are chosen for various frequency bands – 87.5 – 108 MHz, Tuner Gain chosen- 35 dB


control_panel

Centre Frequency

Enter a frequency here: 87.5 MH

Use slider to adjust centre frequency:

Or choose a region from the following:

● FM Radio (88-108MHz)
○ DAB Radio (175-240MHz)
○ Digital TV (470-862MHz)
○ GSM Mobile Signals (800-1000MHz)

Current 108 MH

Gain

Enter a gain value here: 35 dBs

Use slider to adjust gain:

Current 35 dBs

Fig. 4 Frequency spectrum control plan

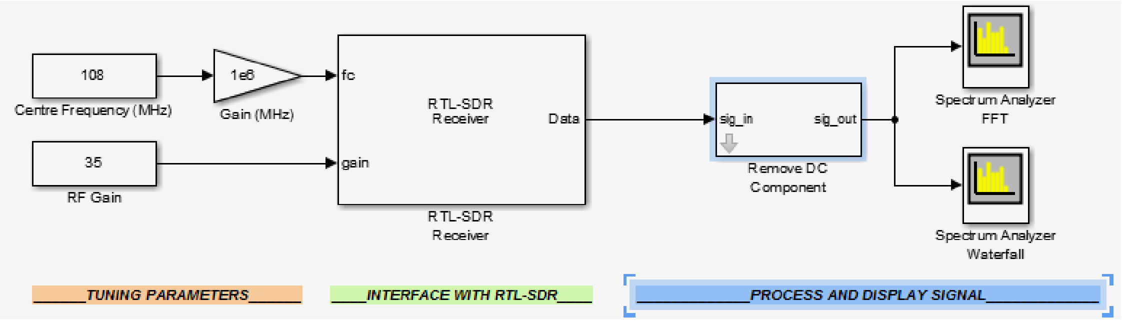


Fig. 5 Simulink model for spectrum monitoring

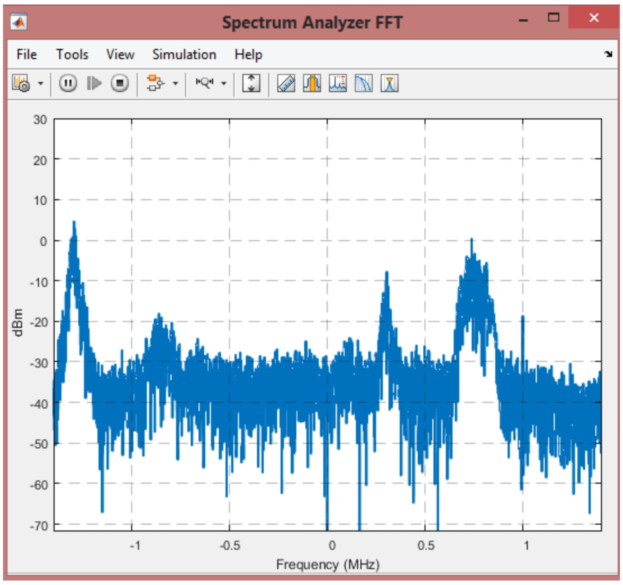


Fig. 6 Frequency spectrum for 94 - 94.9 MHZ

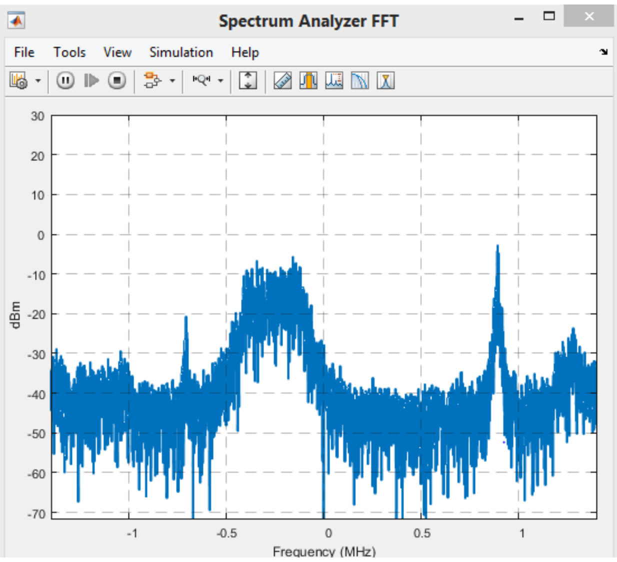


Fig. 7 Frequency spectrum for 95 – 95.9 MHZ

III. SIMULATION, RESULTS AND ANALYSIS

A. Simulation of the Spectrum Sensing and Signal Identification Cognitive Radio Simulink Model

The Simulink model in Fig. 5 was tested in three channels in real time and the results in Table III and Figs. 6 and 7 were obtained.

TABLE III
SIMULATED RESULT OF SIMULINK MODEL

S/N	Primary Signal	Cognitive Decision (H_o/H_1)	Status
1	94.5 MHz FM band	1	Primary Signal absent
2	95.00 MHz FM band	0	Primary Signal Present
3	95.75 MHz FM band	1	Primary signal absent. Only noise Present

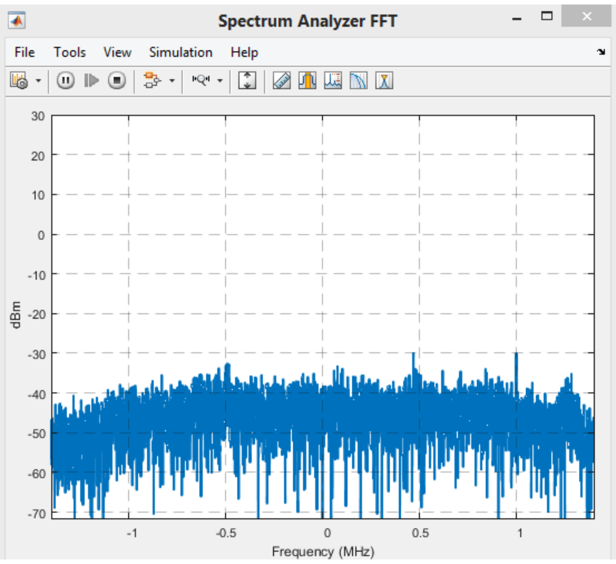


Fig. 8 Frequency spectrum for 102- 102.9MHZ

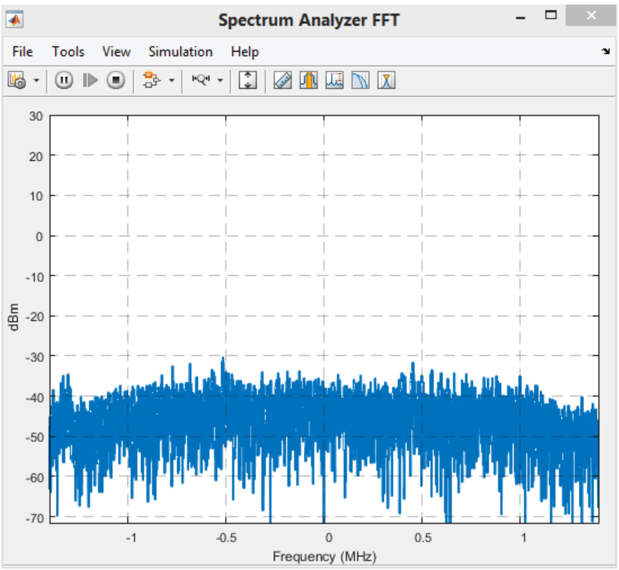


Fig. 9 Frequency spectrum for 103 - 103.9MHZ

TABLE IV
SPECTRUM SENSING IN THE BANDWIDTH ALLOCATED FOR FM (95.750 MHZ TO 95.900 MHZ); CENTRE FREQUENCY SET TO 95.715210 MHZ.

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

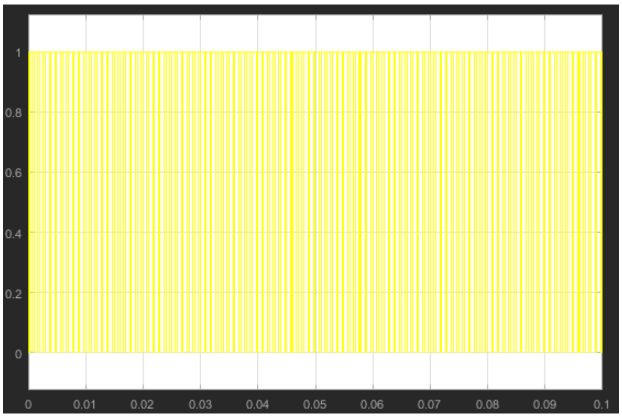


Fig. 10 Spectrum scope showing signal detected

B. MATLAB Simulated Results

Figs. 11 and 12 show the results taken from MATLAB.

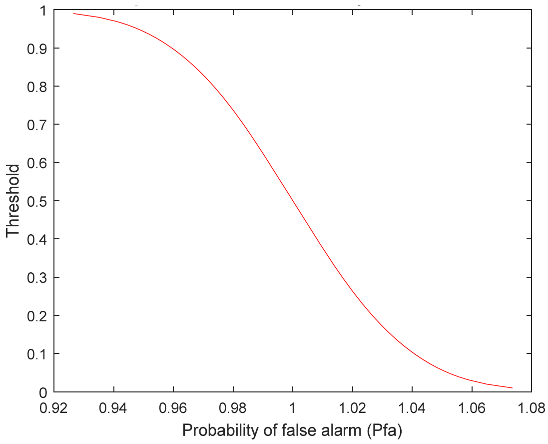


Fig. 11 Detection threshold vs Probability of false alarm

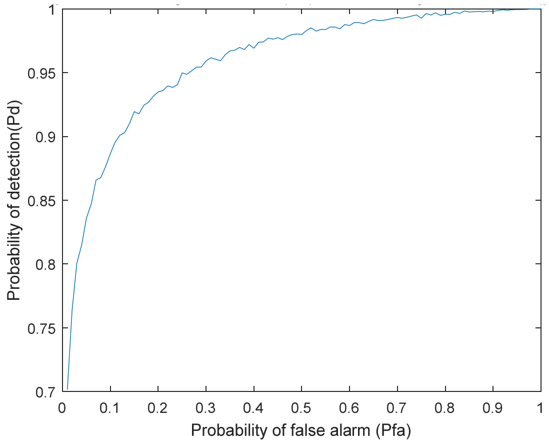


Fig. 12 Probability of detection vs Probability of false alarm

C. Discussion of Results

From Table III, it can be seen that when a primary signal was present in the particular channel or frequency, the MATLAB simulation 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, there was no presence of information signal but only noise; the MATLAB simulation 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

It can be observed from Fig. 11 that the probability of false alarm (Pfa) increased as the threshold gradual decreases and decrease in probability means increase in threshold. Hence in designing energy detectors for spectrum sensing, the probability of false alarm as a design parameter should be kept as such a way that the threshold will be high.

In Fig. 12, the threshold for signal has been simulated, 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 Fig. 11. The probability of false alarm was calculated as energy above threshold divided by number of iteration. The graph shows that as the threshold is raised higher, the probability of false alarm reduces. Hence a reasonable high threshold will reduce the probability of false alarm.

Fig. 12 shows the graph of probability of detection vs probability of false alarm. The curve shows that even in presence of higher probability of false alarm, the probability of detection of the receiver maintains a high stability.

V. CONCLUSION

The spectrum sensing RTL-SDR cognitive radio was implemented in real time and it performed spectrum sensing and signal prediction adequately with little short falls. Cognitive radio is one of the contemporary techniques in the field of telecommunication in order to solve the spectrum shortage problem. Spectrum shortage occurs due to inappropriate use of effective spectrum the prompt boost of the applications in telecommunication which results in increased use of frequency. Hence in order to solve this crisis, spectrum allotment by the NCC plays a significant role in this, (Primary user) individuals who are lawfully allotted to use the spectrum but for secondary user without license to use the spectrum avoiding interference can be done by spectrum sensing as stated in this study. With this key factor, secondary using needs to find the spectrum holes then allocate those hold to the secondary user. For this reason secondary user needs to use energy detection method. From this study it had been observed experimentally that in setting the threshold for signal detection, the probability of false alarm (Pfa) is increased, the probability of detection decreases. Hence in choosing the Pfa as a design parameter, it should be kept as low as possible so as to avoid miss detections.

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