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A Step Towards Enhancing Spectrum Utilization by Implementing a Spectrum Sensing Cognitive Radio Using an RTL-SDR

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Abstract – *In this paper, a spectrum sensing cognitive radio using the RTL-SDR interfaced with Simulink in MATLAB was developed. It performed spectrum sensing and signal prediction between the ranges of 25MHz to 1.5GHz, the tuner range of the RTL-SDR. The RF spectrum occupancy was explored by choosing specific centre frequencies between 25MHz to 1.5GHz in real time using the RTL-SDR. Tests were carried out in real time to ascertain the workability and efficiency of the RTL-SDR cognitive radio. The efficiency of the cognitive radio reduced as the false alarm probability increased. The cognitive radio's efficiency also reduced in high noise signal floors.* ***Copyright © 2018 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Software Defined Radio, Spectrum Sensing, Cognitive Radio, Primary User, Secondary User, False Alarm Probability (P_{fa}), Probability of Detection (P_d), Probability of Miss Detection (P_{md})*

Nomenclature

	Description
$y(t)$	Received signal
$x(t)$	Transmitted signal
$n(t)$	Additive White Gaussian Noise [db]
h	Channel gain [db]
H	Hypothetical user presence
P	Probability of false alarm, detection or missed detection
T	Detection Statistics
$w(n)$	Received noise energy
$X(n)$	Received signal energy of primary user
N	Observed sample
Greek Notations	
σ	Covariance
λ	Threshold
Λ	Test Statistics
Subscripts	
0	Null
1	Primary user
fa	False alarm
d	Detection
w	Noise
x	Signal
md	Missed detection
f	Pre-determined setting
n	Gaussian noise

I. Introduction

Communication governing bodies such as the FCC (Federal Communication Commission), who are in charge of regulating the way and manner in which radio spectrum is utilized in the United States and the NCC (Nigeria Communication Commission) in charge of radio spectrum regulation in Nigeria, regulates the use of the RF spectrum and have assigned various bandwidths to various communication bodies that make use of the spectrum. In all of these countries, the major tool used by the government for spectrum management is a licensing system through bidding [1]. In this system of licensing the spectrum are apportioned into blocks for some specific uses, and specific users or companies are assigned the licenses for the use of these blocks [2].

These allocated bandwidths are fixed to the respective bodies. Due to the limited frequency span of the RF spectrum (3 kHz to 300GHz), it appears that there is a problem of spectrum scarcity as new applications and services arise from time to time. Bandwidth assignment for new applications is one of the main causes of spectrum scarcity. The RF spectrum will always be subjected to routine allocations based on application needs. The major focus of latest wireless technologies is among others, optimal bandwidth utilization, Quality of Service, Higher data rates and latency. Above all, these new communication technologies most basically require larger bandwidths [3]. However, most of these services do not fully utilize the spectrum assigned to them, so this have led to the phenomenon of spectrum holes or spaces whereas new applications are contending for available free spectrum for usage. The once and for all allocation of radio spectrum that gives exclusive right of using the spectrum to the licensed owners has been observed as the main cause of both spectrum underutilization and spectrum artificial scarcity [4] and [5]. Due to this situation, communication researchers came up with the concept of making radio technology, cognitive. A radio is

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said to be cognitive if it can adapt to statistical changes in the operating environment. A cognitive radio can change its modulation technique, the power of its transmitter and the frequency of its carrier. By this, it becomes both intelligent and re-configurable. One most important capability is that it scans the environment network, discovers different spectrum holes and makes inferences and then adapts to the environment. Cognitive radio in itself is built upon the platform of Software Defined Radio (SDR). A radio in which modulation, demodulation and filtering of signals can be performed on software regardless of the hardware part can be termed software defined radio. In this case, adjustment can be made to the radio to fit a need at a particular point in time without necessarily changing the hardware part.

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. These four aspects are Spectrum Sensing, Spectrum Decision, Spectrum Sharing, and Spectrum mobility. Amongst these four steps, spectrum sensing is said to be a very fundamental part regarding the functionality of cognitive radio. In spectrum sensing, a cognitive radio uses its ability to sense any part of the spectrum within its frequency range of signal detection and then it can know when to use the spectrum for its transmission and reception. In this paper, spectrum sensing have been exploited using a software defined radio known as the RTL-SDR (a receive only device). The RTL-SDR is a USB device that receives RF radio signals. This device was initially designed to function as a Digital Video Broadcast-Terrestrial (DVB-T) receiver, but some researchers discovered that it can be used as a generic (receive only) Software Defined Radio (SDR) by changing its mode to test mode. In test mode, the SDR is picks up all signals in its operating range. This operating range usually spans a bandwidth much larger than the Digital Television Range (DTV) for which the receiver was designed. The range in which the tuner operates varies with respect to the components used to build the RTL-SDR but is most commonly from 25MHz to 1.5GHz. For this work the RTL-SDR is interfaced with Simulink in which the basic software operations are performed.

II. Existing Spectrum Underutilization Solutions

Some Technologies are already in place with the goal of meeting the rising demand for spectrum and efficient utilization of spectrum.

II.1. Heterogeneous Networks

The idea of heterogeneous networks involves utilizing a wide range of base stations embedded in the cells of the network to enhance the per unit area spectral efficiency.

This is mandatory to support the growing node density, alongside the cell traffic in mobile networks.

Heterogeneous networks, moreover, have been envisaged to meet future growth of traditional cellular networks. This will include a different mix of cells and base stations that utilize very low power, examples being Pico-cells (250mW–2W), Femto cells (100mW or below) and high-speed WLANs. Users may have to be switched between macro-cells, Femto cells, Pico-cells and the WLANs [6].

II.2. Abstract Cooperative Communications

This technique has been seen to improve reliability and data rate together in a multiuser environment by exploiting distributed spatial diversity amongst others.

The cooperative MIMO, multi-cell MIMO and relaying are examples of cooperative techniques. Less power can be utilized between the source and the destination when it is facilitated by relaying for either single-user or multi-user. Users at the edge of a cell usually experience the unpleasant effect of uneven line-of-sight propagation. Researchers have suggested the use of a distributed system of antennas formed from the antennas of users' devices (Cooperative MIMO).

Cooperative MIMO has been judged effective in this regard since it is an hybrid model of conventional MIMO and some cooperative methods. Co-channel interference arising from the number of users in a typical MIMO network and frequent frequency reuse can be lessened by multiple cooperative cells, known as multi-cell MIMO.

High-capacity wired backhaul links can be utilized in establishing cooperation for multi-cell base stations [7].

II.3. Multiple-Input Multiple-Output (MIMO) Communications:

Spectral Efficiency has been improved by utilizing MIMO systems. These systems permit high data production by ensuring that all antennas have the same total transmit power without any additional use of spectrum. Cell size can be made smaller and transmit power as well as the overhead channel training reduced by utilizing massive MIMO having large-scale antenna arrays [8]. In spite of these sophisticated technologies, spectrum scarcity is still creating challenges for spectrum regulatory agencies. A promising solution to these challenges is the cognitive radio system [9]. The Shared Spectrum Company (SSC) has been a lead in the spectrum management development solutions, and this has been advancing the use of RF spectrum efficiently for over ten years. The SSC carried out an analysis on spectrum usage at some time in 2009 for a period of three and a half day. The analysis was majorly interested in the RF spectrum bands between 30MHz and 3GHz. The analysis made from the data collected shows that a large portion of the RF spectrum is underutilized ranging from satellites band through GSM, Wi-Fi, to TV bands. The World Radio communication Conferences (WRCs) being convened by the International Telecommunication union (ITU) is geared towards allocating the spectrum frequencies to radio communication services. For the purpose of frequency allocation, the world is shared into three regions. The country Nigeria is in region one. All administrations must stay put to their respective allocations [10]. When the power measured at a particular frequency goes beyond a specified threshold, that frequency is termed occupied. Based on the noise floor for a particular band of interest we can determine the threshold value to be chosen for that band [11].

III. Spectrum Sensing Techniques

The major task of a radio that is cognitive is sensing.

When sensing, the radio spectrum is scanned for unoccupied frequency bands and engaging it while at the same time avoiding the spectrum that is occupied by primary users [12]. There are two objectives in mind when performing spectrum sensing: They are: one to make certain that a cognitive radio or secondary user avoids interfering with a primary user and two, to aid cognitive radio or secondary user to spot out and utilize the spectrum holes for the required quality of service.

The job of discovering unoccupied frequency bands in a radio spectrum can be viewed as an on/off or binary challenge. The first part being the absence of signal or information in the frequency band (H_o) and the second, the presence of signals in the frequency band (H_1). If H_o is true, a spectrum hole or unoccupied frequency is detected [13]. [14] showed that spectrum sensing using cognitive radio can reduce network traffic congestion in congested areas by utilizing empty channels. Spectrum sensing in cognitive radio shows its applicability to radio frequencies only and studying the unused spectrum of a licensed user is very important to a cognitive radio [15].

In order to enhance the probability of detection, spectrum sensing can be inference-based, cooperative and transmitter enabled [16].

III.1. Transmitter Detection

The presence (H_o) or absence (H_1) of unoccupied radio spectrum using the transmitter detection method is a binary problem whose hypothesis can be modelled as shown in Equation (1):

$$H_o : y(t) = n(t), H_1 : y(t) = h(t) + n(t) \qquad (1)$$

The cognitive radio can detect the presence or absence of primary users in a frequency spectrum independently using this model [17], [18], [19].

The cognitive radio's primary duty is to sense the presence (H_o) of an unoccupied frequency band ('no signal transmitted") or the absence of an unoccupied (H_1) frequency band ("signal transmitted"). If the received signal is represented as $y(t)$, the transmitted signal as $x(t)$ and the Additive Gaussian Noise (AWGN), $n(t)$ of null mean and variance, (σ_n^2), then $h(t)$ is the channel coefficient that is a measure of the channel gain's amplitude. The solution to the binary hypothesis problem in Eq. (1) gives the cognitive radio its spectrum sensing ability. Cyclostationary feature detection, energy detection and matched filter detection are the three schemes that can be used for spectrum sensing in transmitter detection mode [20], [21]:

III.2. Matched Filter Detection

[22] first suggested the use of the matched filter detection technique to sense the presence or absence of signals in a radio spectrum. This technique of sensing the radio spectrum has been dubbed excellent, due to its ability to optimize received signal-to-noise ratio (SNR).

This technique is also called the coherent detector.

This method gives the best result when the waveform of the radio signal and its carrier is known. The technique involves matching the radio signal with a time shifted version of itself. The output of the filter is compared with a pre-set threshold to determine the presence or absence of signals or primary users in the spectrum. It is quite rare for an inaccurate result to be obtained using the matched filter detection method for spectrum sensing, especially when the radio frequency waveform is known beforehand [23], [24].

III.3. Cyclostationary Feature Detection

When the spectrum sensing technique involves differentiating the modulated signal from additive noise [25], then it is termed cyclostationary [26]. A signal is cyclostationary if its mean and autocorrelation are periodic.

Detection using cyclostationary features require the extraction of certain features from the signal. This is particularly useful when the signal has a very low signal-to-noise ratio. This computation (differentiating noise from useful signal) is complex and mathematically involving. In fact, this complexity is the main disadvantage of the cyclostationary feature detection technique.

The cyclostationary feature detection technique makes use of salient characteristics of the primary user signal to perform its differentiating function. In cyclstationary detection, all frequencies contained in the spectrum of concern are used to compute the spectral correlation between the noise and useful signal.

This makes it possible to use cyclostationary feature detection to differentiate between dissimilar signals. On this score, the cyclostationary feature detection method beats the energy detection method [26], [27], [31].

III.4. Energy Detection

Rayleigh's theorem gives a means of estimating the energy E stored in a signal $x(t)$. This is clearly illustrated in [28]. The theorem is mathematically stated in Eq. (2):

$$E = \int_{-\infty}^{\infty} \left|x(t)\right|^2 d(t) < \infty \qquad (2)$$

If the Fourier transform *X*(*f*) of the signal *x*(*t*) exists besides other criteria that must be satisfied as seen in then:

$$\int_{-\infty}^{\infty} \left| x(t) \right|^2 d(t) = \int_{-\infty}^{\infty} \left| x(f) \right|^2 (f) \tag{3}$$

The energy of a signal is preserved in the frequency and time domain but the frequency domain presents the most flexible way of dealing with the energy stored in a signal. The decision to analyse a signal in either the time or frequency domain does not in any way alter the result that will be got after measurements and parameters are taken. In [29] spectrum analysis was done using the hypothesis expressed mathematically as shown in Eq. (4).

It was an energy detection model. The model for any signal received by an energy detector is presented as:

$$T = \frac{1}{N} \sum\nolimits_{t=1}^{N} \left| y(t) \right|^2 \tag{4}$$

The final decision as to whether the spectrum is occupied or unoccupied is made after a comparison is done between the decision statistics *T* and the pre-set threshold. The probability of false alarm (P_{fa}) and the probability of detection (P_d) form the descriptive parameters of the energy detector. It is a false alarm when the hypothesis returns a decision in favor of H_1 when the decision ought to be H_o. This probability (P_{fa}), called the probability of a false alarm is expressed mathematically as:

$$P_F = P_r(T < {}^{\lambda}\!/_{H_0}) \tag{5}$$

When the hypothesis correctly returns a decision in favour of $H_{1,}$ It is termed the probability of detection (P_d). This is shown mathematically by Eq. (6):

$$P_D = P_r(T < {}^{\lambda}\!/_{H_1}) \tag{6}$$

A good detector has a low probability of returning a false alarm (P_{fa}) whilst having a high probability of accurately detecting the presence of signals in a spectrum (P_d). Good detectors optimize bandwidth utilization without negatively influencing the quality of service. A lot of researches in the area of spectrum sensing using energy detection are still being carried out.

IV. Methodology

The binary hypothesis problem forms the basis of spectrum sensing and this problem is expressed mathematically by Eq. (7) and Eq. (8):

$$\begin{aligned} &H_0 : y(n) = w(n) \\ &n = 1, 2 ....N \end{aligned} \tag{7}$$

$$\begin{aligned} &H_1 : y(n) = x(n) + w(n) \\ &n = 1, 2 ....N \end{aligned} \tag{8}$$

The H_o hypothesis says the received signal *y*(*n*) has only noise samples *w*(*n*) and no primary user (PU) signal. When the received signal has both noise signal and primary user signal, the hypothesis returns the decision, $H_{1,}$ clearly indication that the spectrum is occupied:

$$y(n) = x(n) + w(n) \tag{9}$$

Ideally spectrum detection would mean hypothesis H_1 for primary user (PU) present and hypothesis H_1 otherwise. But due to mistakes in spectrum sensing and the stochastic nature of spectrum utilization in practice, some new terms are defined to handle this drawback in mistaken detection. The terms are missed detection (*md*) and false alarms (*fa*). Following the stated definitions, two probabilities can be used to summarize the performance of any spectrum sensing algorithms. They are:

Probability of Missed detection given by:

$$P_{md} : P(H_0 / H_1) \tag{10}$$

or complimentarily, the Probability of Detection:

$$P_d : P(H_1 / H_1) = 1 - P_{md} \tag{11}$$

and Probability of False alarm:

$$P_{fa} : P(H_0 / H_1) \tag{12}$$

In practice, large P_d and low P_{fa} values are desirable with some trade-off, necessary.

Probability of False alarm (P_{fa}): This probability decides that the signal is present whereas Ho is true, that is:

$$P_{fa} : P_r(T > \lambda / H_0) \tag{13}$$

Probability of Missed-detection (P_d): This probability decides that the signal is absent whereas H_1 is true, that is:

$$P_{md} : P_r(T < \lambda / H_1) \tag{14}$$

Detection probability (P_d): This probability decides the signal is present when H_1 is true, that is:

$$\begin{aligned} &P_d : P_r(T > \lambda / H_1), \\ &\text{thus}, P_d = 1 - P_{md} \end{aligned} \tag{15}$$

In this paper, the probability of false alarm was arbitrary chosen to calculate the detection statistics which was then compared to the chosen threshold.

IV.1. Test Statistics, T

An energy detector decision test statistics is given as:

$$T = \sum_n \left(y[n] \right)^2 \tag{16}$$

The received signal, $y(n)$ is used to determine the test statistics, T (the summation of the square of the samples (n) of the received signal).

IV.2. The Spectrum Sensing Cognitive Radio

An energy detector decision test statistics can be modelled as shown in Fig. 1.

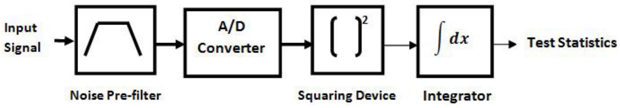


Fig. 1. Bock diagram of the Energy Detector

The Energy Detector implemented was used to achieve the following:

i. Perform 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. The test statistics is computed from the power spectrum density and compared with a statistically generated threshold to decide whether a spectrum is occupied (has a primary user signal) or not.

The detection threshold is derived using statistical approaches. The value of this threshold is dependent on the maximum noise energy, the number of samples form the test statistics and a selected probability of false alarm.

IV.3. The Spectrum Sensing Cognitive Radio System Using RTL-SDR in MATLAB Simulink

The model used for spectrum sensing in this paper is non-cooperative. In non-cooperative spectrum sensing, individual devices or secondary users carry out spectrum sensing locally. Thus each individual device or secondary user senses the presence or absence of primary users' signal in the spectrum [30]. The system block diagram for the spectrum sensing cognitive radio is depicted in Fig. 2.

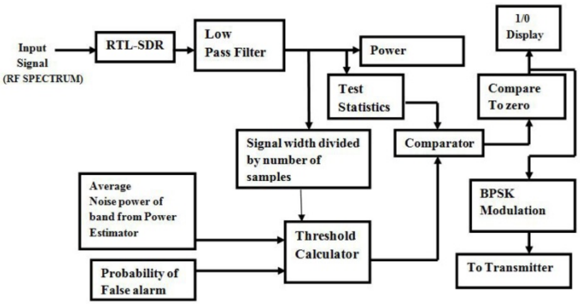


Fig. 2. Block diagram of spectrum sensing cognitive RTL-SDR Simulink radio

IV.4. The Mode of Operation of the Spectrum Sensing Cognitive RTL-SDR Simulink Radio

The mode of operation of the entire system can be summarized as follows- the RTL-SDR is tuned to the centre frequency of the band whose primary signal is of interest, the RTL-SDR receives the signal, performs sampling and the analogue to digital conversion of the signals. It then outputs the samples to the PC where the Simulink model is interfaced with the RTL-SDR. The Simulink model has a low pass filter which receives the sampled signal and its function is to control the noise in the band and ensure the variance of the signal is normalised. The signal is then passed on to the power estimator which measures the signal energy and calculates the noise power. The received signal from the RTL-SDR after low pass filtration is also passed on to the test statistics calculator, where the signal is passed through a Kaiser window to allow the required band of frequencies and then it is magnitude squared. The coefficients of the allowed frequencies are got by passing the squared signal through an FFT block. These coefficients are then summed up and the absolute value of the result is taken since the result comes out as a complex number. The absolute output of the summer is the test statistics. The width of the signal, which is the number of samples present in the signal and two other constants, that is the average noise power of a known frequency band and a selected probability of false alarm are fed into the threshold calculator, to get a set threshold. The average of the test statistics is also taken and compared against the set threshold, from the comparison, the difference of the two signals is taken and the output value is fed into a compare to zero block. If the output value is greater than zero, a one is displayed, predicting the presence of the primary user but if the output value is lesser than zero, a zero is displayed predicting the absence of the primary user signal. The output of 1 or 0 is then modulated unto a carrier signal using Binary Phase Shift Keying (BPSK), so that it can be transmitted to a cognitive engine for spectrum management.

IV.5. Test Statistics

The generated test statistics was checked against the pre-set threshold to define whether a primary user signal was present in the spectrum or not. Eqs. (17a) and (17b) express this mathematically:

$$\Lambda = \sum_{K=1}^{N} \left| y(n) \right|^2 = \sum_{n-1}^{N} (e_r(n)^2 + e_i(n)^2 \tag{17a}$$

$$\Lambda = \sum_{K=1}^{N} \left| Y(K) \right|^2 \tag{17b}$$

The signal, $y(n)$ in the time domain is represented in the frequency domain as $Y(K)$.

The energy detector's test statistics is represented mathematically by Eq. (18):

$$\Lambda = \frac{1}{T}\int_{t-T}^{t} y(t)^2 dt \tag{18}$$

When the traffic in the network is heavy and the variety of users becomes higher, the test statistics is modified as shown in Eq. (19):

$$\Lambda = \sum_{n-1}^{n=0-1} \left|y(n)\right|^2 + \sum_{n=n_0}^{N} \left|y(n)\right|^2 \tag{19}$$

If normalized, the test statistics becomes:

$$\Lambda = \frac{1}{2\sigma_w^2 N}\sum_{N-1}^{n} \left|y\right|^2 \tag{20}$$

IV.6. Threshold Generation

The threshold helps to determine whether the wanted signal is absent or present in the channel.

It is given as:

$$\Lambda_f = \left(Q^{-1}(P_{fa}) + \sqrt{N}\right) * \sqrt{N 2\sigma_w^2} \tag{21}$$

where Q is a Gaussian function.

IV.7. BPSK Transmission of H_0/H_1 to Cognitive Engine

A Binary Phase Shift keying (BPSK) signal can be defined as:

$$\begin{aligned} &V_{BPSK}(t) = b(t)\sqrt{2P}\cos 2\pi f_c t \\ &0 < t < T \end{aligned} \tag{22}$$

where $b(t) = +1$ or -1, $f_c =$carrier frequency, $T =$bit duration, $P =$Signal Power, $A =$Peak value of sinusoidal carrier. The H_0 or H_2 decision from the spectrum prediction is transmitted to a cognitive engine in the case of cooperative sensing for further spectrum management. Given that it's a 1 or 0 decision output, Binary Phase Shift Keying (BPSK) is used for modulation and this modulated signal will be sent to a transmitter which will transmit the decision from the spectrum sensor to a cognitive engine or other cognitive users for spectrum management. The real time implementation of the spectrum sensing cognitive radio using RTL-SDR in Simulink is shown in Fig. 3.

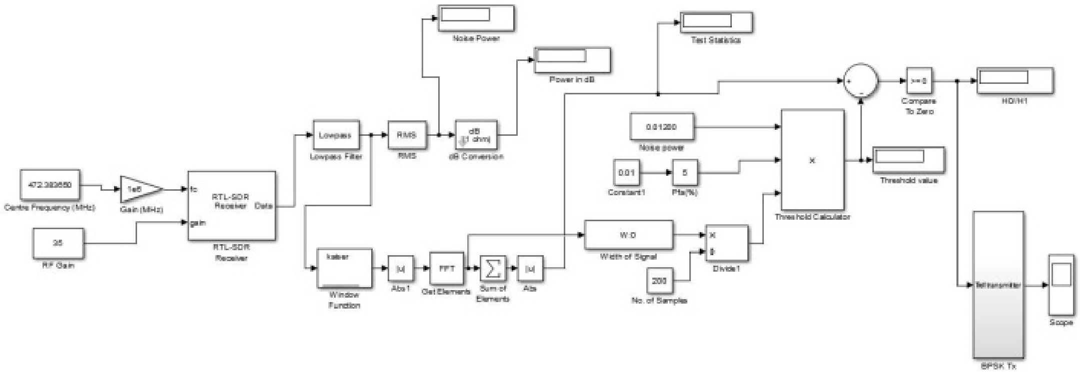


Fig. 3. Complete real time model for the spectrum sensing cognitive radio using RTL-SDR in Simulink

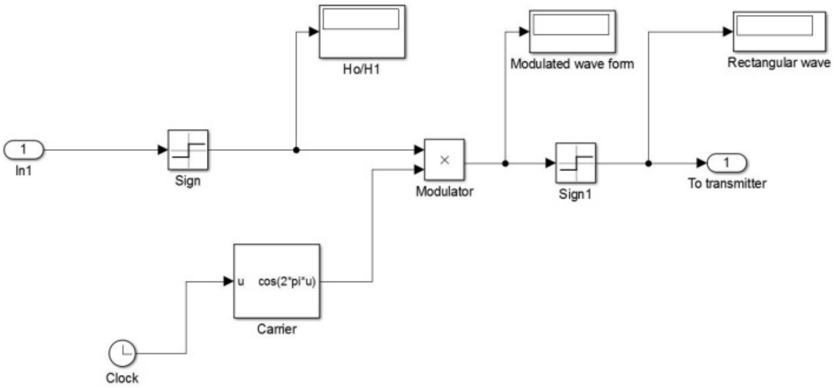
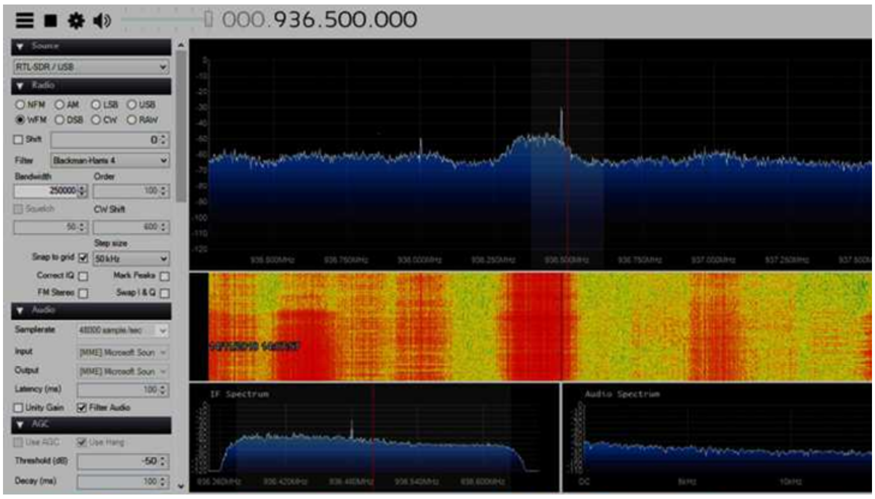


Fig. 4. Real Time model of BPSK modulation of H_0 /H_1 decision in Simulink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Source: RTL-SDR / USB

Radio: ○ NFM ○ AM ○ LSB ○ USB ● WFM ○ DSB ○ CW ○ RAW

☐ Shift 0

Filter: Blackman-Harris 4

Bandwidth: 250000

Order: 100

☐ Squelch 50

CW Shift: 600

Step size: 50 kHz

Snap to grid ☑

Correct IQ ☐

Mark Peaks ☐

FM Stereo ☐

Swap I & Q ☐

Audio

Samplerate: 48000 sample/sec

Input: [MME] Microsoft Soun

Output: [MME] Microsoft Soun

Latency (ms): 100

☐ Unity Gain ☑ Filter Audio

AGC

☐ Use AGC ☑ Use Hang

Threshold (dB): -50

Decay (ms): 100

Fig. 5. Set-up of the RTL-SDR interfaced with the SDR-sharp software

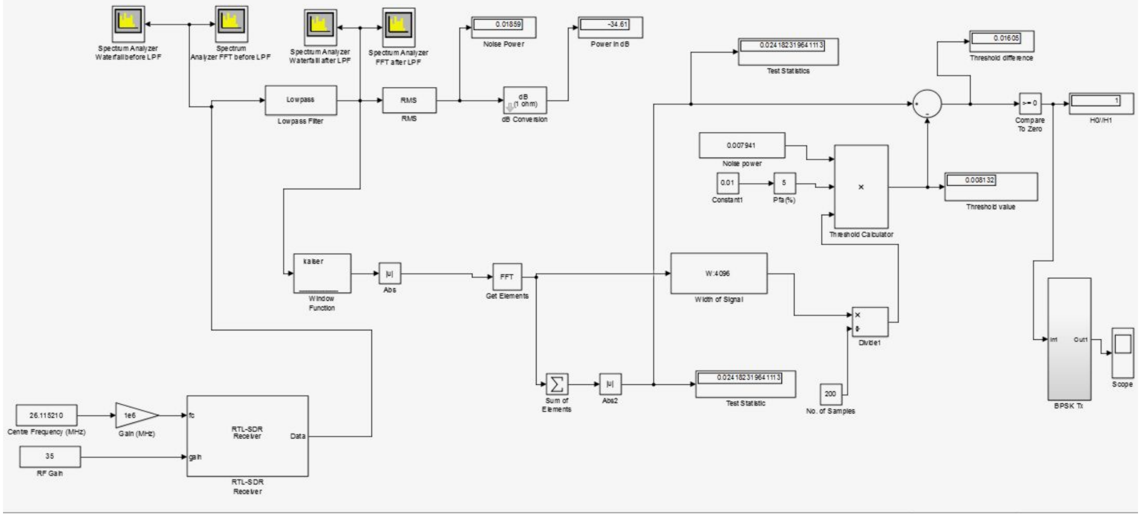

Fig. 6. Set up of the RTL-SDR interfaced with the Simulink model

V. Results and Discussion

Testing of the Spectrum Sensing Cognitive Radio using RTL-SDR in Simulink was done in the spectrum bandwidth allocated for Maritime mobile, broadcasting Land mobile, FM broadcasting, Aeronautical mobile and Space exploration, TV broadcasting on VHF, Fixed mobile and Radio astronomy, Amateur Radio Location and Fixed mobile, Broadcasting Analog TV, GSM Reverse link, GSM forward link, Broadcast satellite, digital audio broadcasting and the RTL-SDR was tuned to the following centre frequencies respectively: 26.115210MHz, 47MHz, 92.700MHz, 138MHz, 223MHz, 322MHz, 430MHz, 472.383650 MHz, 905.300100MHz, 936.339900 MHz, 1.469600270 GHz using the NCC table as guide. The test shows that the spectrum sensing cognitive radio using RTL-SDR in Simulink performed the spectrum sensing and signal prediction adequately, showing the period when the particular bandwidth in which signal is to be sensed with signals, that is primary user present and when it was vacant, that is absence of primary user. It can be observed from Fig. 8 that as the probability of false alarm (P_{fa}) is increased from the range of 1% to 5%, there is a gradual decrease in the probability of detection (P_d) as the P_{fa} goes below 2%. Hence in designing energy detectors for spectrum sensing, the Probability of false alarm as a design parameter should be kept as low as possible. The probability of miss detection (P_{md}) is equal to one minus the probability of detection ($P_{md}=1–P_d$) [3]. Using this equation, the probability of miss detection was plotted against the probability of false alarm (P_{fa}) in Fig. 7. It can be observed that as the probability of false alarm (P_{fa}) exceeds 2%, the probability of miss detections rises sharply. Hence it can be seen from the table of results and during the testing that in most cases as the P_{fa} is adjusted above 2% the toggling between H_0 and H_1 increases gradually in frequency, which points to miss detections.

Fig. 8 shows a relationship between the probability of detection (P_d), the noise power and the probability of false alarm (P_{fa}). It shows a limitation of the energy detector for spectrum sensing.

It can be observed that the probability of detections (P_d) decreases with higher noise level for a given probability of false alarm (P_{fa}). Higher negative noise dB, indicates less background noise. Hence from this it can be inferred from this test using the RTL-SDR that the capability of the energy detector for spectrum sensing degrades with higher noise levels. This was observed during testing when spectrum sensing was performed in the band allocated for GSM Reverse link: 890MHz to 915MHz and in the band allocated for Broadcast satellite, digital audio broadcasting: 1467MHz to 1492 MHz that there was much noise in the band hence the frequent toggling between H_0 and H_1.

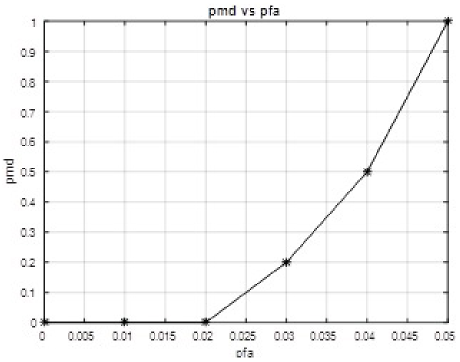

Fig. 7. Graph of probability of miss detection versus probability of false alarm

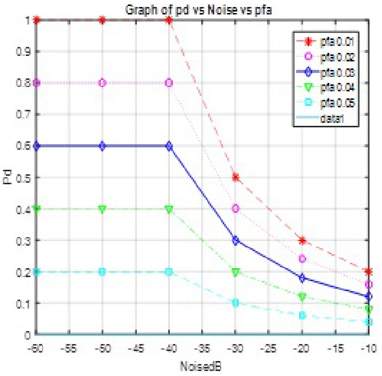

Fig. 8. Graph of probability of detection versus noise dB versus Probability of false alarm

Figs. 9 and 10 show the H_1 and H_0 decision modulated using BPSK unto a carrier, so it can be transmitted to a cognitive engine to aid cooperating with other cognitive users for further spectrum management decisions.

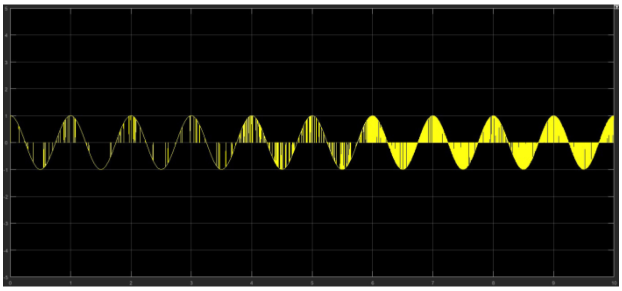

Fig. 9. Graph of H_1 detection modulated into a carrier signal

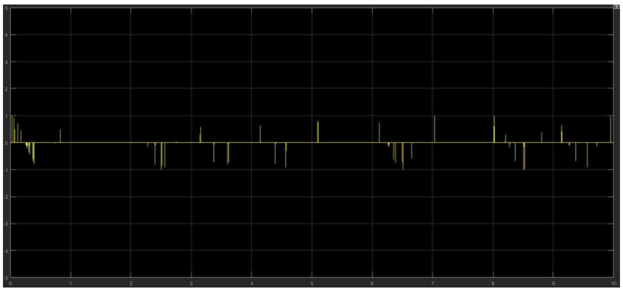

Fig. 10. Graph of H_0 detection modulated into a carrier signal

VI. Conclusion

This work entails the implementation and the analyzing of a spectrum sensing RTL-SDR cognitive radio for enhancing spectrum utilization in MATLAB/Simulink. 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. It was observed in the setting of the threshold for signal detection that as the probability of false alarm (P_{fa}) is increased, the probability of detection decreases. Hence in choosing the P_{fa} as a design parameter, it should be kept as low as possible so as to avoid miss detections. The analyses carried out showed the need for high performance spectrum sensors.

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