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Design and Implementation of the Dynamic Spectrum Access on an Audio Stream in a Congested Environment

F. N. Nwukor [a,*], M. S. Okundamiya [b]

[a] Petroleum Training Institute, Effurun, Delta State, Nigeria
[b] Department of Electrical and Electronics Engineering, Ambrose Alli University, Ekpoma, Nigeria

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ABSTRACT

This paper aims to design and implement the dynamic spectrum access (DSA) on an audio stream in a congested environment. The test approach for the DSA protocol is based on the frequency of selection of five chosen stations and the size of the audio file saved. The implementation of the DSA protocol was done with an FM received coupled with the energy detector and channel selection algorithm using a non-coherent FM demodulation procedure and the register transfer level - software defined radio (RTL-SDR) in MATLAB environment (version 2018b). The analysis of the results for the DSA protocol implemented in the FM receiver showed that the 97.3MHz station is active compared to the remaining stations.

1. Introduction

The constraints on the allotment and use of the radio frequency (RF) spectra is fast increasing owing to the growing demand for wireless applications [1]. Byun et al. [2], suggested the concept of cognitive radio (CR), to advance proficient utilisation of the RF spectrum. The CR permits flexible usage of frequency bands, not being utilised by the primary (licensed) users. However, there could be problem of falsification in the use of spectrum. As a consequence, measures to guard against such attacks are vital for the success of the CR networks (CRNs). One of the most effective methods to resolve these drawbacks in CRNs is the dynamic spectrum management [3], with high level of security. The essentials and challenges of the CR in dynamic spectrum allocation and sharing spectrum are discussed in the literature [4, 5]. CR has the ability to optimally modify operating constraints in line with the adjoining radio environment. Its ability to recognise and exploit the vacant spectrum band permits the coexistence with inherent radio systems, and improve spectrum utilisation without impairing the licenced users [6].

DSA, also referred to as dynamic spectrum management (DSM), is a set of procedures based on the probability and network information concepts, being explored and established to enhance the performance of communication networks [7-10]. The concept of DSM is a common trait amongst the internet-of-things (IoT) literature, and is dependent on enabling technologies. The specific type of enabling technology is dependent upon which layer of the IoT architecture is being considered. There are different detection methods for spectrum sensing [5]. Nonetheless, energy detection comprises a promising method for spectrum sensing in CR due to the widespread

* Corresponding author
E-mail address: francesnkem@gmail.com
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applicability and simplicity [11]. In [1], an efficient energy detection scheme for optimum performance of CR. The authors proposed an evolutionary probability theoretical approach towards long-term self-coexistence to identify a signal using an estimated noise signal in a security system.

Different collaborative spectrum sensing schemes are described in the literature with varying trust parameters comprising pre-filtering and simple average blending schemes [12], and malicious intent and location reliability [6)], The approach adopted by the authors does not cater for a multi-stage spectrum sensing and the possibility of a smart jamming attack by malicious nodes. Several probability theoretical approaches have been presented in literature to defend against various attacks in the collaborative spectrum sensing of CRNs [13-16]. The common theme in all of these defence strategies is hop to a channel that might not be jammed.

Also, the management and control access to the radio spectrum is crucial to mitigate interference and protect the licenced users [1]. The television white space (TVWS) regulations have set the basis for guidelines, which can be employed for potential frequency bands (radio spectrum) of interest [17]. To provide sound spectrum access control for the radio spectrum, these same TVWS regulations structure can be implemented in Nigeria. Though, the TVWS regulations provide interference mitigations for the primary user, they do not provide regulations on protecting secondary TVWS device users from interfering with each other. Both users (the primary and secondary) must be protected from interference. The realistic environment in which CR technology is applied, is usually more complicated and volatile than the assumptions in research [17]. Based on the consideration to modify the models to describe the real conditions more accurately, the components of the analytical framework of CRN can be improved to adapt the realistic situations.

In this paper, the design and implementation of the DSA on an audio stream in a congested environment with energy-based method of spectrum sensing, is considered under a practical scenario.

2. Methodology

2.1. Design

The design uses MATLAB program 2018b, R2832U DVB-T and personal computer core i7. Nevertheless, it should be noted other computer can be use; however, the computer should be able to run MATLAB 2018b and work with MathWorks. FM demodulation process in MATLAB uses the RTL-SDR in the commercial FM spectrum. As illustrated (Fig. 1), the received complex signal from RTL-SDR is passed concurrently through 2 blocks. The first block takes the complex FM signal to transform the phase, which produces the conjugate of the complex FM signal whereas, the second block inserts a time delay, τ to retire the signal [18]. The mathematically assumed single tone FM modulated signal in its complex baseband representation are described in equations (1) – (11).

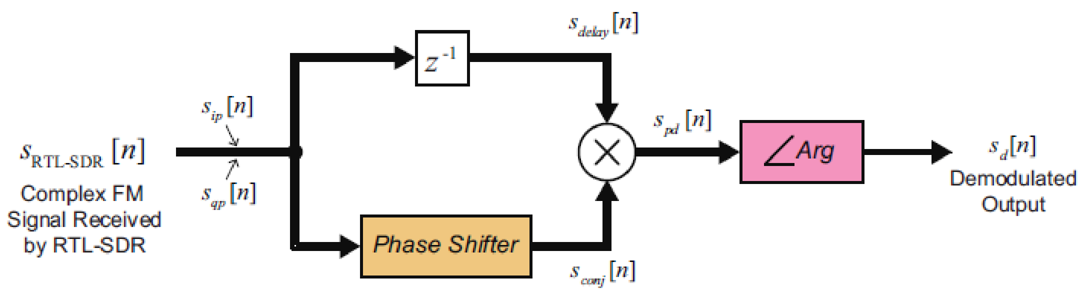

Fig. 1 FM signal receiver by RTL-SDR.

Statistically, assume that a single tone FM modulated signal in its complex baseband representation is given as equation (1).

$$S_{FM}(t) = \frac{A_c}{2} e^{j(\omega t + \theta_{FM}(t))} \qquad (1)$$

Where, S_{FM}(t) is the carrier component and A_c is the amplitude of the carrier.

The delayed signal, $S_{delay}(t)$ and the phase shifted signal or conjugate signal, $S_{conj}(t)$ would be defined by equations (2) and (3), respectively; these signals being combined via phase detection as expressed in equation (4).

$$S_{delay}(t) = \frac{A_c}{2} e^{j\left(\omega(t-\tau)+\theta_{FM}(t-\tau)\right)} \tag{2}$$

$$S_{conj}(t) = \frac{A_c}{2} e^{-j\left(\omega t+\theta_{FM}(t)\right)} \tag{3}$$

$$S_{pd}(t) = S_{conj}(t) \times S_{delay}(t) = \frac{A_c^2}{4} e^{-j[\omega t-\omega(t-\tau)+\theta_{FM}(t)-\theta_{FM}(t-\tau)]} \tag{4}$$

$$\angle S_{pd}(t) = -[\omega\tau - \omega(t-\tau) + \theta_{FM}(t) - \theta_{FM}(t-\tau)] \tag{5}$$

When τ is very small value, then;

$$S_d(t) = \angle S_{pd}(t) = -\left[\frac{d\omega t}{dt} + \frac{d\theta_{FM}(t)}{dt}\right] \tag{6}$$

Solving equation (6) will give equation (7).

$$S_d(t) = -[\omega + \theta_{FM}(t)] \tag{7}$$

From FM modulation of message signal m(t) [19]:

$$\theta(t) = 2\pi\left(f_c + k_{FM} m(t)\right)t = \omega t + 2\pi k_{FM} m(t) t \tag{8}$$

Therefore;

$$\theta'(t) = \omega + 2\pi k_{FM} m(t) \tag{9}$$

and

$$S_d(t) = -[\omega + 2\pi k_{FM} m(t)] \tag{10}$$

Equation (10) specifies that the argument of phase detected signals vary proportionally to the fundamental signal $m(t)$ with a DC offset. In order to demodulate received broadcast signal from advanced FM radio station some information must be considered. The multiplexed (MPX) FM modulated signal can be expressed as follows [18]:

$$S_{FMMPX}(t) = A[S_i(t) + S_r(t)] + A[S_i(t) - S_r(t)] + cos(2\pi f_{38k} t) \\ + B\, cos(2\pi f_{19k} t) + C[S_{rds} t]\, cos(2\pi f_{59k} t) \tag{11}$$

Where, A = 45%, B =10%, C = 5.2%.

With this information, it should be noted that after employing an FM demodulator to restore the FM, multiplexed to baseband, stereo FM receivers must implement de-multiplexing and decoding so as to extract the channels (left and right). To implement this demodulation in MATLAB, a discrete time representation of the demodulated signal of the received FM signal (Fig. 1,), is shown in MATLAB code:

$$S_d[n] = \angle\left\{\left(S_{ip}[n] - S_{qp}[n]\right) \times \left(S_{ip}[n-1] + S_{qp}[n-1]\right)\right\} \tag{12}$$

Where, $S_{ip}[n]$ is the in-phase component of the complex RTL-SDR signal and $S_{qp}[n]$ is the quadrature phase component.

The design of the DSA on an audio stream in a congested environment with energy-based method takes the approach of FM demodulation of signals (latitude 6.3999, longitude 5.6138) using phase delay discrimination method while implementing the DSA protocol. The test approach is based on the frequency retuning of 5 chosen stations and saving audio files for each DSA protocol carried out (mainly for measuring throughput). For this study, 5 consecutive stations were chosen starting with 97.3MHz station; being an active station compared to the remaining stations chosen consecutively. Hence, one can clearly spot mistakes or unexpected outcomes. Fig. 2 displays the MATLAB command showing the information of the USB connected SDR.

```
>> my_rtlsdr = sdrinfo

my_rtlsdr =

                RadioName: 'Generic RTL2832U OEM'
             RadioAddress: '0'
              RadioIsOpen: 0
                TunerName: 'R820T'
             Manufacturer: 'Realtek'
                  Product: 'RTL2838UHIDIR'
               GainValues: [29×1 double]
      RTLCrystalFrequency: 28800000
    TunerCrystalFrequency: 28800000
             SamplingMode: 'Quadrature'
             OffsetTuning: 'Disabled'

>>
```

Fig. 2 Information of the RTL-SDR used for spectrum analysing.

The name of the connected device is given by the key, RadioName. Also, the device is connected to the first USB port. Hence, its radio address is 0 (it should be noted that when there is only one USB port in use, it becomes the first USB port, i.e., the RadioAddress will remain at 0). Other properties include the tuner used by the SDR, which is R820T, the manufacturer of the SDR, the product model, the possible gain values (range from 1 – 29), the crystal frequency used for the product and that of the tuner, as well as the modulation and demodulation technique, which is quadrature amplitude modulation. There is also the property showing whether the OffsetTuning is enabled or disabled. The software-defined radio used for this study is the RTL-SDR by NooElec (Fig. 3); in terms of the feature of its design, the concept of in-phase/quadrature complex signal (IQ) samples, and components of its design (the tuner, R028T and the receiver model, Realtek).

Fig. 3 NooElec variant of RTL-SDR.

2.2. MATLAB Implementation of FM Receiver with DSA

The DSA test-bed in the congested environment (lat. 6.3999, long. 5.6138) with energy detection and channel selection were implemented for the FM receiver designed in MATLAB. The setup is equivalent to the CRN of a single user in a busy primary user (PU) active spectrum with the difference of no secondary user (SU) receiver. A complete setup of a CRN demonstration includes an SU transmitter and receiver for communication in a congested PU active spectrum. However, this little setup is enough to demonstrate a DSA protocol as the CRN protocol (consisting of the spectrum management; spectrum sensing, spectrum access and spectrum mobility [3]) developed in the transmitter section of communication while the receiver section listens for the signal it can decode in the spectrum for the chosen channels. An alternative to a complete CRN setup can include a section/program for the CRN/DSA protocol, which then communicates via a different communication protocol (e.g., TCP) to the transmitter and receiver of the CRN. This approach appears to be much supportive in terms of SU throughput. As this study aims to demonstrate DSA protocol in the simplest form possible, an FM receiver with DSA protocol will clearly test the spectrum sensing, management, access and mobility of the implementation by comparing the results of the 300s test and the expected outcome as well as the plot of the number of selections and back-offs that occurred in the process.

CRN protocol comprises the spectrum sensing, which make up the physical (PHY) layer, the spectrum management, spectrum access and spectrum mobility (which make up the higher layers including the PHY layer as well). The MATLAB code is pictorially demonstration in Fig. 4.

```
Function: FM_receiver_with_DSA
   % set basic parameters for system objects
   % define audio system object
   % perform calculations for set of 5 channels
   % initialize timer for back-off
   % initialize parameters for CSA/MAC layer
   % implement MAC layer while communicating with PHY layer operations sensing and receive functions
   % plot number of selection and channel frequency selected

      Function: sensing
         % initialize RTL-SDR system object
         % implement -10dB energy detector program for spectrum sensing on selected frequency
         % release RTL-SDR object

      Function: receive
         % initialize RTL-SDR and other system objects
         % implement FM demodulation of selected frequency
         % save audio file
         % release all initialize system objects
```

Fig. 4 Demonstration of an entire overview of the large number code lines.

Fig. 4 illustrates an entire overview of the large number of code lines. A close observation of the above representation shows that the higher MAC layer has to interact with the spectrum sensing part of the CRN protocol (at the physical layer) and the spectrum access part as well (at the physical layer too), while the MAC & PHY layer takes care of the spectrum mobility of the CRN for this simple demonstration (as it can get more complex than this). Throughput of the implemented DSA protocol is recorded, given by the size of audio file save (length of file in seconds).

3. Results and Discussion

The DSA results are presented in Figs. 5 - 6 for 5 FM channels and the number of selections in those channels. This test was carried out for two scenarios with different runtime, one for 300 seconds and the other for 600 seconds. The two scenarios showing runtime and bytes saved (file size) are shown in Table 1. Here, the analyses of the results for the DSA protocol were implemented in the FM receiver which was presented. The test approach for the DSA protocol is based on the frequency of selection of the chosen 5 stations and the size of the audio file saved (for measuring throughput). For this study, 5 stations were chosen, consecutive stations starting with 97.3MHz, and based on the analysis, it was noticed that the 97.3MHz station is active compared to the remaining stations. Hence, when an error is made (or unexpected outcomes), it can be spotted.

Table 1 Summary of results for FM receiver with DSA protocol.

Scenario	Description	Number of channels detected	Number of selections	File size	Recording time
Scenario 1	Detect free channels	1	13	2.16MB	23 sec
Scenario 2	Detect active channels	1	7	1.28 MB	13 sec

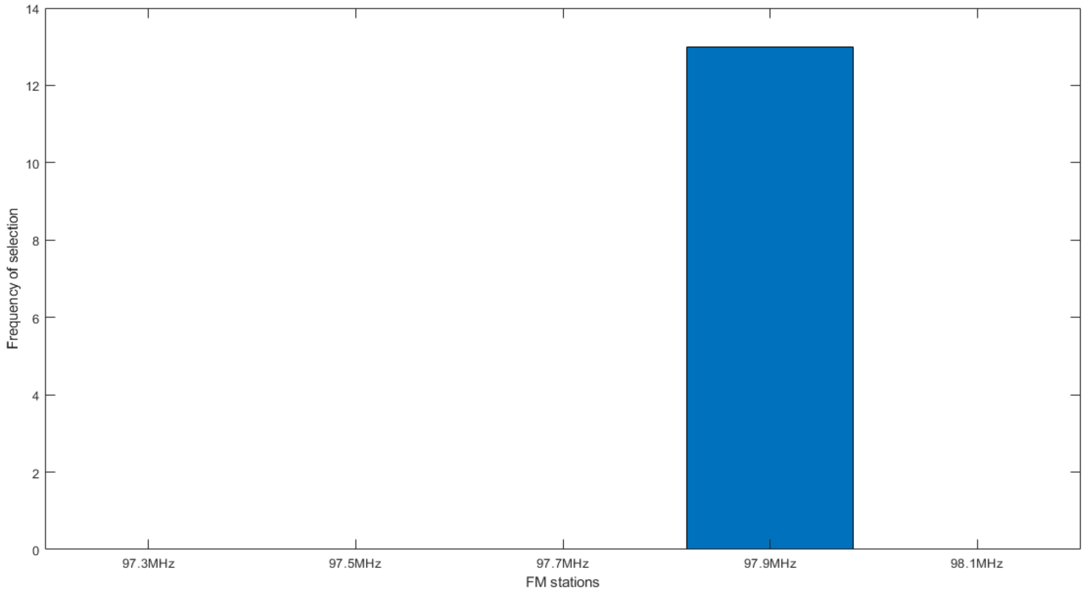

Fig. 5 DSA Protocol with Normal Testing, Selecting the Most Inactive Channel.

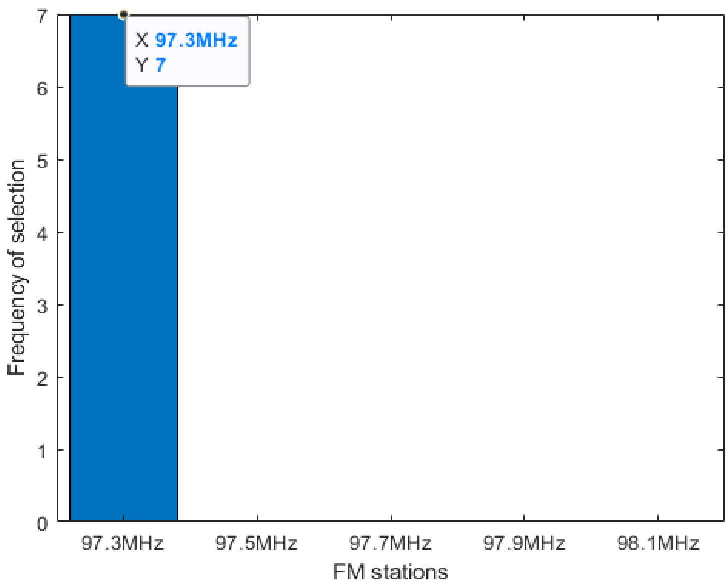

Fig. 6 DSA Protocol with Reversed Testing, Selecting the Most Active Channel.

Fig. 5 shows a 100% selection of station 97.9MHz in a processing time of 300s. It is the result of the testing of the DSA protocol whereby the spectrum sensing signifies when an FM station is absent for the DSA protocol to receive the selected frequency for an inter-sensing time of 5s. This is expected as the rest was done to give every FM station an equal chance of selection. The selection was done based on the result of the sensing part of the DSA protocol because 97.9MHz and 98.1MHz are the most-idle channels in the set of channels considered; the most active is 97.3MHz and then the next two.

Fig. 6 shows a 100% selection of station 97.3MHz in a processing time of 300s whereby the saved data is done for 5s. It is the result of a reversed testing of the DSA protocol whereby the spectrum sensing signifies when an FM station is present in order for the DSA protocol to receive the selected frequency for an inter-sensing time of 5s. Also, the saved audio file played for a total of 35s as expected (Table 1).

4. Conclusion

In this paper, the design and implementation of DSA on an audio stream in a congested environment has been established. The test approach for the DSA protocol is based on the frequency of selection of five chosen stations and the size of the audio file saved. The demonstration of DSA protocol was done with an FM received coupled with the energy detector and channel selection algorithm using a non-coherent FM demodulation procedure and RTL-SDR. The analyses of the results for the DSA protocol in the FM receiver showed that the 97.3MHz station is active compared to the remaining stations.

Conflict of Interests

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

ORCID

M. S. Okundamiya https://orcid.org/0000-0003-3365-4759

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