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Improving the Wideband Spectrum Sensing In Cognitive Radio Using Optimization Technique of Hard/ Soft Fusion for Power Minimization

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Abstract
Spectrum underutilization and scarcity problems have been addressed by cognitive radio (CR) technology. The spectrum holes can be detected and opportunistically used by CR enabled-devices. However, the issue of dynamic spectrum sensing needs to be adequately solved in order for cognitive radio technology to significantly make an impact on the industrial sector and businesses. Thus, this new hard and soft fusion technique was proposed to overcome the CR network sensing issue. The objective function of the hard and soft fusion model used in this work for sensing of spectrum was to minimize sensing power and increase throughput of the system. Java was used to implement the hard and soft fusion model that had been designed. The advanced Cisco packet tracer 7.0 was set up and used for the simulation. The simulation results revealed that in terms of throughput and reduction in spectrum sensing energy, the proposed hard and soft fusion model performed better than the Maximal Independent Set (MIS). The hard and soft fusion model developed outperformed the MIS algorithm in throughput by 61.1%. Using the MIS as a baseline, it decreased energy consumption for spectrum sensing by 22.8%.

Keywords: *Cognitive radio, Wideband spectrum, Cooperative sensing, Hard and soft fusion, Cisco packet tracer.*

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I. INTRODUCTION

The major challenge facing the development of wireless communication networks is the insufficiency of radio frequency (RF) spectrum. There is a tremendous increase in demand for high data throughput, smart devices and social media services which put pressure on the demand for larger bandwidth of frequency spectrum. Government regulators like the Federal Communications Commission (FCC) in the United States of America, and the Nigeria Communication Commission (NCC) in Nigeria, etc, are responsible for the licensing of frequency spectrum for network operators and other users [1]. This frequency spectrum is statically allocated based on request over a given period of time within a geographical location. However, research findings have shown that for a reasonable amount of time, the licensed spectra are underutilized by licensed owners. These research findings also suggested that CR network is a likely technology that can help to overcome the issue of spectrum under-utilization and handle the growing demand for large bandwidth [2]. This technology allows those who do not have the license to operate in the authorized band whenever it is made available while ensuring that the authorized users do not suffer interference [3]. Research findings also showed that CR can be useful in maritime communication. Ships and submarines when built with CR capabilities can sense the radio environment for unused spectrum in the absence of unlicensed users [4]. This will help to reduce path loss problem as a result of radio atmospheric signals and geographical location. Accessing spectrum white spaces requires good sensing technique that is efficient and fast in detecting spectrum holes for secondary users while at the same time provides protection to primary users against interference. Energy detection sensing method is commonly used in this regard. Its common drawback is the effect of log-normal shadowing and fading thereby making it hard for the unauthorized users to differentiate between an empty and a faded band. Cooperative spectrum sensing is used to reduce sensing performance degradation [5][6]. Although, cooperative spectrum sensing can help mitigate the drawback of energy detection method, it also requires adequate sensing algorithms to improve the general network.

This work seeks to improve the wideband spectrum sensing using hard and soft fusion detection method for cognitive radio. The improvement focuses on secondary users sharing collected sensing information among them. Each user uses the shared information to decide on the condition of the spectrum. This helps to reduce degradation in sensing performance caused by log-normal shadowing effect. Hard and Soft fusion rules are two major algorithms used by the fusion centre to collate one-bit local decisions. Various mathematical models to improve resolution on a primary user exists within a given frequency band. However, work done on the available spectrum sensing technique suggests that most of the recent spectrum sensing works focused on primary transmitter detection based on local observations of secondary users [7-10].

Cooperative sensing has been suggested to solve the issues confronting sensing of spectrum, such as shadowing, noise uncertainty and multipath fading. This sensing method also helps to ease problems associated with hidden PU and reduces time of sensing [11]. Different adaptive algorithms were found in literature for the implementation of threshold setting in soft fusion schemes. They include: square-law selection (SLS), square-law combining (SLC), maximal ratio combining (MRC), selection combining (SC) and for the hard fusion scheme, these were seen: AND, OR and Majority combining [12-14]. No explanation on developments in spectrum sensing was provided. Study [15] showed the usage of CR for 5G communication. These studies focused on ways of meeting the demands by exploring the spectrum resource and maximizing the utilization of its bands. However, spectrum scarcity creates a serious challenge in achieving an efficient and optimum throughput. [16] offered an overview of recent spectrum sensing approaches. However, current applications like the Internet of Things (IoT) and paradigms like Full-Duplex are not covered. [17] presented numerous spectra sensing characteristics.

The authors in [18], suggested a dynamic threshold based on controlled false alarm probability (Pf) as part of the new cooperative distributed PUs detection. Although the model significantly improved process of sensing with respect to detection and false alarm probabilities with a minimized error, but it failed to address the issue of energy efficiency in cooperative distributed PUs in the model. [19] presented two matched filter methods: single matched filter and cooperative matched filter detectors both with adaptive threshold in order to solve detection problem due to noise uncertainty and hidden PU problems during spectrum sensing. These two methods were evaluated using probability of detection (Pd), probability of misdetection (Pm) and Pf. Findings from these showed that cooperative matched filter detector performed better than the single matched filter detector in terms of SUs precision in detecting PUs presence although the work did not focus on energy used during sensing. However, there is no evidence from literature that showed that the method of optimization has been applied to solve CR power allocation and spectrum sensing issues using hard and soft fusion techniques which is the objective of this work. The rest of the paper is organized as follows: Section 2 presents the theoretical frame work on cooperative sensing, while section 3 describes the materials and method. Results and analysis are discussed in section 4. Finally, section 5 concludes the paper.

II. COOPERATIVE SPECTRUM SENSING

Detection of primary user signal is fraught with fading, shadowing and uncertainties. To surmount these challenges, researchers suggested cooperative spectrum sensing as a solution because this solution could mitigate hidden node problem as well as reduce time of sensing [19-23]. This sensing scheme suggests that sensing of spectrum white spaces and detection of PUs signal be done together by all CR users or nodes within the vicinity. The local information gathered by all CR users can be shared among them before being sent to collation centre called fusion centre which uses it to make an informed binary decision about the presence or absence of a hole or primary user [24]. It is proper in cooperative sensing that all CR users transmit local decision on spectrum sensing as observed in a one-bit form due to limited communication bandwidth. Centralized, external and distributive sensing are the three ways cooperative sensing can be performed [25-27].

2.1 Centralized Collaborative Sensing

This approach in Figure 1, uses a central unit known as fusion centre (FC) to collate all the SUs local one-bit binary decisions and finally decide whether or not a primary user is using a band of frequency. Fusion centre can use various fusion algorithms namely, hard and soft fusion rules to collate local sensing information. The decision that assures the existence of PU is then spread to all the SUs by the fusion centre or sometimes the fusion centre directly controls the traffic [26].

2.2 Distributed Collaborative Sensing

The approach also depicted in Figure 2 is like a mesh arrangement in which all the SUs within a given area share sensing information among themselves and each use the information received together with its own knowledge to decide finally about the PU presence. This approach is less expensive because it does not need a centralised structure such as fusion centre but each SU is furnished with a sensing unit. It also enhances true detection probability while ensuring that the false alarm probability is reduced. We can use spectrum load smoothing algorithms to implement this type of cooperative method in cognitive radio devices according to [28].

(2a) Sensing of spectrum in centralized form
(2b) Sensing of spectrum in distributed form
Figure 2: Cooperative spectrum sensing forms [25]

2.3 Relay-Assisted Spectrum Sensing

The relay assisted spectrum sensing method can improve cooperative sensing performance if an SU observing a strong sensing channel and a weak report channel and another SU with a weak signal and a strong report channel correlate and collaborate and send the sensing results to the fusion centre. Each SU serves as a relay in assisting another to send sensed data to the fusion centre in order to determine the presence or absence of a PU [29].

III. MATERIALS AND METHOD

The Hard/soft Fusion Rule model is adopted for cognitive radio because it improves spectrum sensing and avoid underutilized spectrum. The decision of deploying SUs for optimum use for the given spectrum led to the development of the Hard/Soft Fusion Rule model. The model which is to be built in a java software will address the issue of choosing the spectrum sensing for allocation. To determine the minimum bandwidth of the SUs, analysis of spectrum is conducted using the adaptive modulation code (AMC) and log-distance path loss model.

3.1 Experimental Measurement and Data Collection

Data from MTN Nigeria, a network operator, was gathered for this project's case study of a cognitive radio network. MTN network is configured based on CISCO RFSS network controller. The controller's radio system P25 channel oversees radio assignment and access. It compiles and saves data about radio network traffic. The controller's traffic log is used to extract snapshots of radio network traffic statistics for data collection. The network's performance data contained in the snapshots was retrieved and tabulated as shown in Table 1.

3.1.1 Network Traffic Channel Simulation Parameters

3 second data sampling window; 13 radio frequency channels, each with a bandwidth of 0.1 MHz; 15 watts of transmission power; Duration of time slots: 625 seconds.

Table 1: Network traffic statistics collection [MTN DATA set]

Records interval (3secs)	Number of channels occupied	Number of channel unoccupied	Number of SUs	Number of PUs	Average spectrum sensing duration (seconds)	Waiting Queue	Active radio session
1	118	2	45	73	4.56	3	113
2	120	-	40	80	8.86	16	109
3	116	4	59	57	6.42	8	116
4	111	9	25	86	4.98	4	106
5	114	6	34	80	3.97	7	108
6	120	-	70	50	8.27	18	118
7	120	-	30	90	7.98	12	117
8	110	10	40	70	5.98	8	104
9	120	-	18	102	9.06	20	116
10	109	10	60	49	5.65	13	104

3.2 The Proposed System Block Diagram

Figure 3 shows the elements involved in the wideband spectrum assignment algorithm designed for cognitive radio networks.

Figure 3: Block diagram of the elements of the system proposed

The algorithmic design discussed in this section took into account a cognitive radio network with m primary users and n secondary users. Primary users can only use the portion of the spectrum that is licensed. Secondary users take advantage of empty spaces in the principal user's spectrum to send data because they lack any licensed spectrum of their own

3.3 Assumption Made in this Research

Assumption directed connectivity graph is used to model the multi-hop wireless connection; where are nodes with finite set, with , while the unidirectional wireless link is represented by taking from node Vi to node also known respectively as node i and node j.

Primary users are represented by the nodes from the subset while the secondary users are represented by the nodes from subset . All secondary users are expected to have cognitive radios containing a scanner and a reconfigurable transceiver. The transceiver can select from a set of adjacent bands of frequency where the cognitive radio's maximum bandwidth is represented by .

In this work, it was anticipated that numerous transmissions might take place simultaneously in a band of frequency using various spreading codes as an example. It was supposed that the free spectrum was divided into two channels that are distinct where:

i. Secondary users use presumptively time-slotted common control channel for spectrum access negotiations.

ii. Data communication was conducted over a data channel (DC).

Also, a set of discrete mini-bands each having a discrete index and bandwidth as contained in the data channels. As an instance, this mini-bands set which i SUs select between and having bandwidth as represented by the interval . In this case, the cognitive radio's highest bandwidth is denoted by , where the mini-bands' maximum number is denoted by fB, and the cognitive radio's maximum bandwidth constraint is represented by fi fB. On the control channel , where ϵ [fmin;fmax.], each backlogged SUs competes for access to use spectrum . Local information is shared among all secondary users on the common control channel. Multi-hop routes are used to carry traffic flows. We assumed demands of traffic include a set and of unicast session. A pair of fixed source-destination node define each session. Sessions' arrival rate at node i is indicated as (t), while the arrival rates vector is indicated by λ. Each session's different queue is maintained by each node for which it is either a source or an intermediate relay. At time slot t, define (t) as the number of queued packets for sessions waiting for transmission at secondary user was defined as the transmission rate on link for sessions during time slot t, and R as the vector of rates. For SU, the queue is updated as follows: λ

(= (1)

3.3 Development of a Hard/ soft Fusion Rule Model for wideband Spectrum Sensing

The purpose of designing this model is to enhance wireless network spectrum sensing for cognitive radio mesh network. It minimizes the consumption power by the secondary user. The reduction in energy will reduce the issue of underutilize space and improve the quality of service.

Let Ps represent the utilized power for channel while the SUn dissipated energy for sensing channel m be denoted by .and are the same. Hence, we can express energy utilization Es for sensing of channel in the form of equation 2

SUs use energy not only to sense the channels but also to transfer sensing result to CBS (cognitive radio base station). It was believed, irrespective of the number of channels sensed, that a single packet of sensing report should be sent by each SU, and that there is enough time of reporting for all packets of the SUs to be located.

We denote the energy used to report the result of sensing to CBS by , and this hinges on how SUn and CBS are relatively positioned. Additionally, we take Srep to represent the SUs group that carry out sensing in this frame and must inform the CBS about their local decision. All the energy used for reporting is then expressed below as

The model of optimization and its decision variables employed for spectrum sensing are initially defined.

Assume = {1, if channel m is sensed by SUn} {0, else}

= {1, if sensing result is transmitted to CBS by SUn } {0, else}

Equation 4 below is the required Tm,n for a given value.

Additionally, from equation 3, we can calculate the sensing time denoted by which SUnneed to realise a value of 0.5. The expression for is given below

Let cooperating SUs minimum number for a channel be defined by and by our assumption in this model, let at least SUs sense a channel. is a design criterion choice. We also choose for this design, a value of greater than 1 so as to encourage cooperation and enhance robustness. Let ,

then is given by

Since th , We can calculate , which represents the cooperating SUs maximum number as follws:

Where the probability of false alarm for another threshold is . This is to say that the cooperating SUs maximum number needed for the cooperation false alarm constraint is actually . For the case where there are different values of , we can employ the method of solution used here as well. We can express optimization problem1 below as the optimization problem:

Subject to the following constraints:

th
{0, 1}
( )
Where is defined as s

Thus, the multiplication above will receive a contribution of 1 and (1 -) from SUs with Xm,n value of 0 and 1 respectively. The overall energy used for frame sensing is reduced by the objective function in (8). Constraint (9) specified that if channel M is sensed by SUn, the duration of sensing should be at least . An SU's total sensing time according to constraint (9) must be less than or equal to the frame's sensing period. Additionally, if Yn=0 it sets all values of related to SUn to zero. According to Constraint (9a) at least SUs should sense each channel. In order to reach the threshold of probability of false alarm constraint (9b) restricts the number of cooperating SUS for a channel. If an SU senses any channels, constraints (9c) cause the Yn value for that SU to be 1. Cooperative probability of detection must be higher than the threshold for each channel according to constraints (9d). Finally, Constraints (9e) and Constraints (9f) specify the type of variables. The pseudo code used for the sspectrum sensing is presented as Algorithm 1.

Algorithm 1: Spectrum Sensing Algorithm Pseudo Code

```
Require: Pd, , M, N, Ym,n, Tm,n
Time remaining [n] = Tm,n for all n
Srep= ,Snrep = {SU1, SU2 ,…, SUN}
for m = 1 to M do
    Sort SUs in Srep in descending order of Ym,n
    Index_Rep= the sorted entries indices list
    Assignment_No = 0, k = 1
    While (assignment No < )&& (k < |Srep|) do
        n = Index Rep[k]
        Choose SU_nϵ Srep as a candidate and compute value of Tm,n to get Pd
        If Tm,n< Time remaining [n] then
            Time remaining [n] = Time remaining [n] – Tm,n
            assignment No = assignment No + 1
        end if
        k = k + 1
end while
If Assignment_No< then
    Sort SUs in Srep in decreasing order of Ym,n and let index Nrep be the list of indices of the sorted entries
    k = 1
    While (Assignment_No< )&& (k <= |Srep|) do
        n = Index Nrep[k]
        Choose SUnSnrep as a candidate and compute value of Tm,n to get Pd
        If Tm,n< Time remaining [n] then
            Time remaining [n] = Time remaining [n] - Tm,n
            Assignment_No = Assignment No + 1
            Srep = Srep∪{SU_n}
            Snrep = Snrep ) \ {SU_n}
        end if
        k=k +1
    end while
    end if
end for
```

Srep is group of SUs in Algorithm 1 that will sense and transmit frames reports. The SUs' group yet to be given access for channel sensing is denoted by Snrep. At first, Srep= ,Snrep = {SU1, SU2, …. SUN}. In order to conserve energy for reporting, the system initially searches for SUs among those in Srep. The process will switch to Snrep if SUs detected are not sufficient. For the channel under consideration, the processing of Srep SUs and Snrep SUs are done in descending arrangement of Ym,n values. SUs is used for each channel sensing. Calculating the necessary value of Pd (false detection probability) involves:

Pd = max {1 – (1 – thQd) 1/ , } (11)

With this is ensured which is minimum detection probability. The direction of sensing for a frame is Ts where Ts = ∑Tm,n}.

3.5 Development of Spectrum Decision Algorithm

This algorithm makes decision in terms of the SUs (i.e. the channels) selected for data transmission. The spectrum units, M (the size of spectrum pool) that available, are frequently fewer than the SUs' bandwidth needs i.e. .Bj is the required spectrum units for jth SU. Therefore, algorithm for sharing of spectrum has to strategically decide the SUs that should have access to the unused spectrum, and which unit of spectrum that should be given to which SUs. All SUs corporate in maximizing the overall throughput of cognitive radio network by choosing a subject of the SUs which are of better conditions for spectrum access. The pool size of the spectrum is the limitation of this optimization problem.

Let the needed data be denoted by Rj for the jth SU (j {1, …, N}), that is equal to R1 for class1 user. The SU problem of optimization selection with overall cognitive radio network throughput objective is given as N SU sets, and a shared spectrum pool with M spectrum units, choose a subject for the SUs in a way that

Xj = 0 or 1, j {1, 2… N}; where

Algorithm 2 and 3 are run in succession to achieve the optimal solution for this problem of selection of spectrum.

Algorithm 2: First Module for Solution for Spectrum Selection Problem

```
Initialize matrix with row j = 0,1..N and column m = 0, 1..M, and set all entries in the first row and column to zero. Algorithm 2 uses Algorithm 1 output which is matrix V.
for j = 1: N
        for m = 1: M
                If Bj< = m
                        If Rj+ >+
                                + = Rj + +
                                end
                else
                        + = +
                end
        end
end
```

Algorithm 3: Second Module for Solution for Spectrum Selection Problem

```
Initialize j = N, m = M, and xj = 0, j = N, where j = 1 … N
The algorithm 3 input argument is matrix V which is algorithm 1 output
While j, m > O
    if Vmj V
        Mark jth SU user as selected user: xj = 1
        j = j – 1, m= m – Bj
    else
            j = j – 1
        end
end
```

Vector x is the Algorithm 2 output which shows the SUs that were chosen for transmission of data. Specifically, jth SU is chosen if xj = 1. It should be noted that the solution which is best for any cognitive radio network having n (n) SUs and pool of spectrum having (m M) units of spectrum is included in the algorithm 1 solution (for the cognitive radio network with N SUs and M units of spectrum), when the best sub set of SUs is chosen by algorithm 2 to run spectrum allocation, that maximizes the overall cognitive radio network throughput.

IV. RESULT ANALYSIS AND DISCUSSION

Java programming language was used to implement Hard/Soft Fusion rule model. Through Common Object Request Broker Architecture (COBRA), the Hard/Soft Fusion rule model application communicates with the operating system object of radio network packet tracer. This application enables communication between objects. It enables interoperability between objects created in various programming languages.

Figure 4: Mesh Cognitive Radio network for performance evaluation of developed Model

The cognitive radio network case study built with Cisco Packet Tracer software is depicted in Figure 4. Twenty mesh clients (PUs and SUs) and 5 mesh network routers make up the model. Ten of the twenty mesh clients are PUs and the remaining ten are SUs. Configuration of the mesh client, layer 2 switch, and network router radio parameters is enabled by the program. In order to set up the simulation appropriately, the radio network settings in the packet tracer environment, such as channel counts, transmit power, and burst (slot) time, are defined. Table 1 displays the data that were utilized to build up and configure the simulation environment.

SUs and PUs activations based on Poisson distribution are conducted by the access control script of the mesh client that is loaded by the operating system of the radio network packet tracer. This simulates SUs randomly seeking and yielding channels. As the simulation is running, the logs' statistics and trace files of the network traffic such as queue size, buffer size, routing table, allocated / de-allocated channel numbers of client service sessions and transmit power can be viewed in the memory space of network management of the mesh controller when programmatically accessed. There were 60 iterations in the simulation with 60 seconds duration for each iteration. The simulation trace file's network traffic statistics are programmatically accessed every three seconds throughout each iteration in line with the data sampling window of the network. The network performance data are taken from the simulation trace file and plotted to assess how well the designed algorithm performed. Bytes transmitted, spectrum counts, throughput, energy usage for sensing performance, delays and spectrum sensing duration are collected, tabulated, and plotted from the simulation trace file. The traffic trace file extracts for a 60-second iteration is given as well as MIS (maximum independent set) Java source code for CR networks technique for allocation of spectrum. The same set of data is used to simulate the MIS spectrum allocation algorithm's operation so that its performance may be compared to that of the newly designed algorithm.

4.1 Throughput performance

To assess how effective the developed model algorithm and MIS algorithm are, network performance statistics were retrieved from trace file of the simulation and plotted. Throughput performance of the Developed Hard/ soft Fusion Rule Model for spectrum sensing is shown in Figure 5. Looking at the trends of both figures, it can be seen that there is an improvement in the average throughput performance of the proposed model when compared with the MIS model. While the average throughput of the proposed model is approximately 85 Kbytes/Sec that of MIS model is 29 Kbytes/Sec. This remarkable improvement is as a result of throughput stability of about 121.000kbytes achieved in the proposed model which is lacking in the MIS model.

(5a) Developed Hard/Soft fusion rule model
(5b) MIS Model
Figure 5: Throughput performance of the Developed Hard/ soft Fusion Rule Model

4.2 Evaluation of Energy Used in Sensing

Figure 6 depicts the variations in energy used in sensing in Watts for the developed hard/soft fusion rule model. It can be seen from the graph that energy is expended in sensing for models as more SUs gained access to spectrum. It is important to note that less energy is expended for the developed hard/soft fusion rule model which is approximately 25 Watts on the average than the MIS model which is 33.5 Watts during sensing by the secondary users. This is due to the fact that the newly designed model algorithm for allocation of spectrum is versatile. Therefore, there is less in sensing energy as more holes are effectively detected as a result of having the more adaptable algorithms for frequency allocation. The difference between the two algorithms' sensing energy requirements is clearly depicted in the Figure 7.

(6a) Energy sensing performance of the developed model
(6b) Sensing energy Performance of MIS model
Figure 6: Sensing energy variations in Watts for the developed hard/soft fusion rule model.

4.3 Validation of the Developed Model with MIS Model Based on Energy Sensing

Figure 7: Graph showing the validation of the developed model with the MIS model

The new model's sensing energy rise is less when put side by side with that of MIS model. With at least 20 SUs sensing, the energy rose from about 15 watts to about 34.7 watts. One effect of this is that the newly created algorithm is more effective than the MIS algorithm at detecting spectrum holes.

5.0 CONCLUSION

The issue related to accurate sensing techniques was demonstrated in this work using soft and hard fusion optimization algorithm. The algorithm created was used to determine the SU that will use the free channel in the most efficient manner based on the spectrum sensing minimization. The optimization algorithm's objective function was used to reduce the energy intended for spectrum sensing. The optimization's limitations are cap on the number of cooperating SUs for channels, flags that show whether or not a channel is sensed by SU and limit on sensing time.

Simulated results revealed the level of efficiency of the developed model. A comparison of the two algorithms also revealed that the Hard/ soft Fusion Rule Model performed better than the MIS approach. The newly created Hard/ soft Fusion Rule Model algorithm notwithstanding the rise in radio connection session of the SU had a stable throughput and a throughput that is higher than that of the algorithm of the MIS on the average by 61.1%.

In terms of sensing energy, the MIS's spectrum sensing energy consumption was decreased by 22.8% via the developed Hard/ soft Fusion Rule Model. The Hard/soft Fusion Rule Model demonstrated high adaptability and effectiveness than the MIS technique by using less spectrum sensing energy technique.

References

[1] FCC, "Federal Communications Commission Spectrum Policy Task Force Report of the Spectrum Efficiency Working Group," Fed. Commun. Comm. Spectr. Policy Task Force, vol. 1, no. 1, p. 37, 2002

[2] Joykutty, A.M., Baranidharan, B. "Cognitive Radio Networks: Recent advances in spectrum sensing techniques and security," In 2020 International Conference on Smart Electronics and Communication (ICOSEC), pp. 878–884. IEEE (2020)

[3] Opawoye, I., Faruk, N., Bello, O. W. and Ayeni, A. A "Recent Trends on TV White Space Deployments in Africa," Nigeria Journal of Technology (NIJOTECH), vol. 34 No. 3, July 2015, pp. 556-563, 2015

[4] D. E. Onu, M. A. Ahaneku, M. O. Ezea, H. O. Osuagwu, and U. N. Nwawelu, "Dynamic Spectrum Allocation Access Using Cognitive Radio Networks in a Maritime," Indones. J. Electr. Eng. Informatics, vol. 9, no. 3, 2021.

[5] Bastidas, C. E. C et al., "IEEE 1900.5.2: Standard Method for Modeling Spectrum Consumption: Introduction and Use Cases," IEEE Commun. Stand. Mag., vol. 2, no. 4, pp. 49–55, 2018.

[6] Pastirčák, J., Gazda, J. and Kocur, D. "A survey on the spectrum trading in dynamic spectrum access networks," Proc. Elmar - Int. Symp. Electron. Mar., no. September, pp. 135–138, 2014.

[7] Tohamy, A., Mohammed, U. A. and T. A. Khalaf, T. A "Cooperative Sensing Using Maximum A Posteriori as a Detection Technique in Cognitive Radio Network," 2019 36th National Radio Science Conference (NRSC), Port Said, Egypt, pp. 266-272, 2019.

[8] Shah, H. A., Kwak, K. S., Sengoku, M. and Shinoda, S, "Reliable cooperative spectrum sensing through multi-bit quantization with presence of multiple primary users in cognitive radio networks," 2019 34th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), JeJu, Korea (South), pp. 1-2, 2019

[9] Seo, D. and Nam, H. "A Parallel Multi-Channel Cooperative Spectrum Sensing in Cognitive Radio Networks," 2018 International Symposium on Antennas and Propagation (ISAP), Busan, Korea (South), pp. 1-2, 2018

[10] Zhang, M. et. al. "Distributed cooperative spectrum sensing based on reinforcement learning in cognitive radio networks," AEU - International Journal of Electronics and Communications,2018: 94. 10.1016/j.aeue.2018.07.029

[11] Arjun, K. R. and Surekha, T. P. "Performance Analysis of Wavelet based Spectrum Sensing and Conventional Spectrum Sensing in Fading Environment for Cognitive Radios," Int. Conf. Curr. Trends Comput. Electr. Electron. Commun. CTCEEC 2017

[12] Azmi, M. H. and Leib, H. "Multichannel cooperative spectrum sensing that integrates channel decoding with fusion-based decision," IEEE Trans. Aerosp. Electron. Syst., vol. 54, no. 4, pp. 1998–2014, 2018

[13] Verma, P., Singh, B. "On the decision fusion for cooperative spectrum sensing in cognitive radio networks," Wireless Netw 23, pp. 2253–2262, 2017.

[14] Nallagonda, S., Chandra, A., Roy, S. D. and Kundu, S. "Analytical performance of soft data fusion-aided spectrum sensing in hybrid terrestrial-satellite networks". International Journal of Satellite Communications and Networking, 35(5), pp. 461–480, 2017

[15] Ahmad, W. S. H. M. W. etal. "5G technology: Towards dynamic spectrum sharing using cognitive radio networks," IEEE Access, vol 8, pp.14460–14488, 2020.

[16] Yucek T. and Arslan, H. "A Survey of Spectrum Sensing Algorithms for Cognitive Radio and Applications". IEEE Comm. Surv& Tutorials, vol.11, no. 1, pp. 116–130, 2009.

[17] Awin, F.A., Alginahi, Y.M., Abdel-Raheem, E. and Tepe, K. "Technical issues on cognitive radio-based Internet of Things systems: A survey," IEEE Access, vol. 7, pp. 97887–97908, 2019

[18] Mokhtar, R. A., Saeed, R. A. and Alhumyani, H. "Cooperative Fusion Architecture-based Distributed Spectrum Sensing Under Rayleigh Fading Channel". Wirel. Pers Commun. vol. 124, pp. 839–865, 2022.

[19] Aziz, A., Khalil, G. and Ayoub, Z. "Spectrum Sensing Using Cooperative Matched Filter Detector in Cognitive Radio," Turkish Journal of Computer and Mathematics Education, vol. 15. No. 2, 2024.

[20] Dikmese, S., Lamichhane, K. and Renfors, M. "Novel filter bank-based cooperative spectrum sensing under practical challenges for beyond 5G cognitive radios," Eurasip J. Wirel. Commun. Netw., vol. 2021, no. 1, 2021.

[21] Garg, R. and Saluja, N. "Spectrum Sensing in Cognitive Radio: Components and Methodologies", World Congress on Engineering and Computer Science, San Francisco, USA, October 19-21, 2016.

[22] Ding, G. et al., "Spectrum Inference in Cognitive Radio Networks: Algorithms and Applications," IEEE Commun. Surv. Tutorials, vol. 20, no. 1, pp. 150–182, 2018

[23] Murty, M. S. and Shrestha, R. "Reconfigurable and Memory-Efficient Cyclostationary Spectrum Sensor for Cognitive-Radio Wireless Networks," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 65, no. 8, pp. 1039-1043, 2018,

[24] Fu, Y., Yang, F. and He, Z. "A quantization-based multibit data fusion scheme for cooperative spectrum sensing in cognitive radio networks," Sensors, vol. 18, no. 2, pp. 473, 2018.

[25] Wang, J., Wu, Q., Zheng, X. and Che, J. "Cooperative Spectrum Sensing', Cognitive Radio Systems," InTech, Nov. 01, 2009.

[26] Guimaraes, D.A. and Pietra-Ricci. "Index Detector for Centralized Data Fusion Cooperative Spectrum Sensing," IEEE Trans. Veh. Technol, vol, 69, pp. 12354–12358, 2020.

[27] Xu, M., Yin, Z., Zhao, Y. and Wu, Z. "Cooperative Spectrum Sensing Based on Multi-Features Combination Network in Cognitive Radio Network," Entropy, 24, 129, 2022.

[28] Zhang, W., Guo, Y., Liu, H., Chen, Y., Wang, Z. and Mitola, J. "Distributed Consensus-Based Weight Design for Cooperative Spectrum Sensing," IEEE Trans. Parallel Distrib. Syst. vol. 26, pp 54–64, 2015.

[29] Akyildiz, I. F., Lo, B. F. and Balakrishnan, R. "Cooperative spectrum sensing in cognitive radio networks: A survey," Phys. Commun., vol. 4, pp. 40-62, 2011