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A Proposed Adaptive Hemoglobin-Oxygen Based Algorithm for Cognitive Radio Network

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Abstract- One of the standing challenges in the development of the cognitive radio network, either because of omission of difficulty to address it has been the challenge how to encourage or motivate the licensed user lease its spectrum to the unlicensed user. In this work, this framework has been laid based on the simple natural process based on oxygen-haemoglobin binding algorithm where the association coefficient of allocation oxygen to haemoglobin association increases as the haemoglobin approaches saturation. This technique is seen as a promising framework as the rewards for leasing the radio spectrum increases with increased generosity of the primary user with assumption that the allocated users do not interfere with each other.

Keywords- *Cognitive Radio Network, Licensed User, Unlicensed User, Oxygen-Hemoglobin Association Coefficient*

I. INTRODUCTION

The explosion in the demand for fast and seamless communication in the 21st century has raised concern on the current and future state of communication spectrum. Institutions and individuals have raised question on the fate of the communication spectrum, one of the most pertinent been, if the current spectrum allocation will be able to support innovation and demand. This question was first raised by Joseph Mitola in 1995 [1] where he made a brave prediction that with the current way in which spectrum is been used, the spectrum will no longer be able to support future customer demand as there will no longer be spectrum to be allocated. This is because, communication spectrum is a fixed natural resource and currently almost the entire available spectrum for communication has already been allocated based on data from FCC as shown in figure 1.

Communication spectrum is literally regulated by government [2] and it gives licences to operators who have the sole right to use their assigned band within the limits of their contract. Recent survey in several literature [3-6] have shown however that most of the assigned spectrum is highly under-utilized or completely not in use by those who have been given the right to use the spectrum. This data can also be gotten from any licensed user.

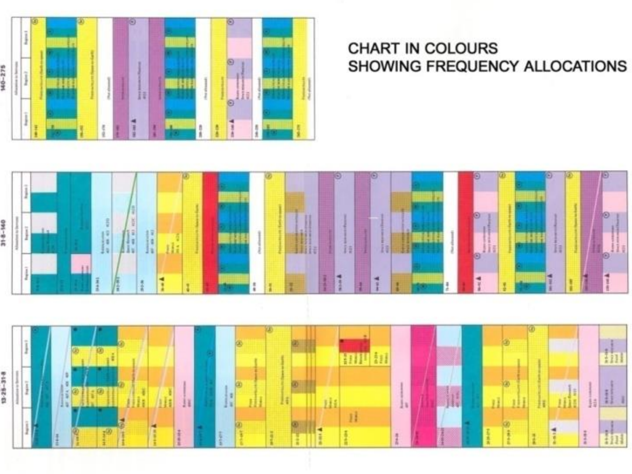

Figure 1. Frequency Allocation Chat

The poor utilization could be due to several factors, such as time, location, transmission power, strength of the receiver among several other factors. Thus leaving this spectrum band idle as prescribed by the spectrum regulator. This can and has been viewed as a poor resource management. Hence a new form of radio that will be able to intelligently identify the underused spectrum and take advantage of the unused resources without causing harm to the licensed user, the cognitive radio was proposed by Joseph Mitola.

The CR has the ability to continuously interact with its environment in real time to determine the appropriate parameters for efficient communication in its environment. The radio does this using three basic principles, namely *spectrum sensing* where the radio continuously monitors the available spectrum band to collect data about it for analysis to identify the spectrum holes; *spectrum analysis*; where the parameters that identify the spectrum holes are detected using the sensed data and *spectrum decision*, where the parameters of the radio such as bandwidth of transmission, data rate and transmission mode are determined. Figure 2 describe the traditional characteristics of a CR in a cognitive cycle

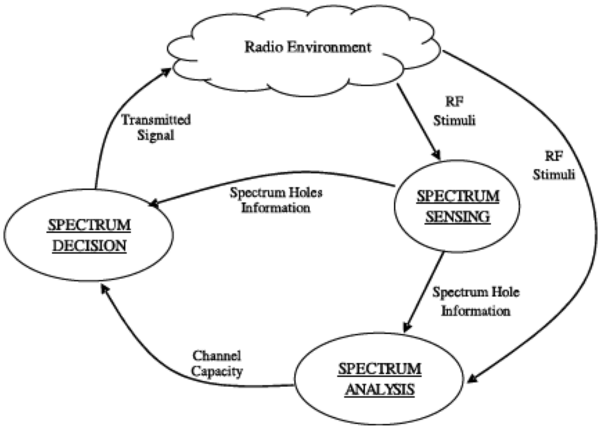

Figure 2. Cognitive cycle, copied from [2]

The cognitive radio is equipped to find the best underutilized spectrum band and use it. It is able to do this by sensing its environment to determine variance in the spectrum, determining which licensed band is best for usage to share with the licensed spectrum. This quality of the CR differentiates it from the conventional radio where only the licensed user uses its transmission spectrum within a defined geography. Traditionally, a cognitive radio is designed as a radio which the unlicensed user only use the licensed band when the band is absent, but this traditional definition could be defined differently if the radio is intelligent enough to use the band even in the presence of the licensed user without interfering with the transmission of the other users. Hence the cognitive radio is defined under three paradymes namely; *overlay, underlay and interweave*. ***Overlay*:** In an overlay approach, the cognitive radio detects the actually transmitted signal of the primary user, and adjusts its own signal in such a way that it does not disturb the primary receiver (PR) even though it transmits in the same band. ***Underlay*:** in underlay, the secondary radio keeps its transmit Power Spectral Density (PSD) so low that its interference to primary users is insignificant. ***Interweave*:** In interweaving approach, the radio first identifies those parts of the spectrum that are not being used at a certain time, and transmits in those; thus, such a radio is called a spectrum-sensing radio.

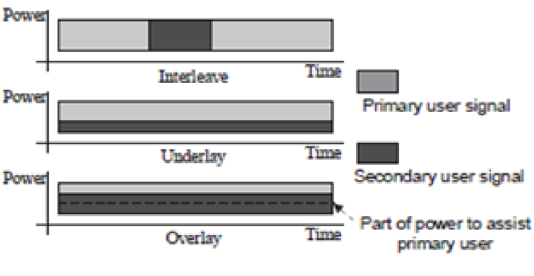

Figure 3. Dynamic spectrum access with temporal spectrum sharing

To achieve any of these three paradigms a sequence of step by step process need to be designed to guide the operation of the unlicensed user. In previous literatures, several other algorithms have been employed to achieve an optimal design of the radio such as genetic algorithm, ant colony, wolf pack, termite hill among several other techniques. In this research, a new type of algorithm hopes to propose which in our opinion serve to address better the challenges of the cognitive radio because of the motivation and reward it offers our network over other previous algorithms.

This paper basically x-rays the ability of haemoglobin in the transport of oxygen and places the qualities side by side with traditional radio with the primary objective of developing an algorithm which is simple and highly efficient for building CR networks.

A. *Spectrum sensing*

There are several methods of sensing radio spectrum that have been reviewed in literature; the most common of these methods are *energy detection*, *matched filter* and *cyclostationary feature detection*. Spectrum sensing is an application of statistically theory to detect the presence of a signal that has been corrupted in noise. It is applied in CR to discriminate between ether the presence or absence of noise in the spectrum. For instance a CR sensing vacant channel must be able to distinguish between a channel carrying only noise and the one carry a signal element in it. Several works have been performed on signal detection theory such as [7-10]. The primary objective of spectrum sensing is to provide for more spectrum access opportunities for the CR user without interference to the primary network, and it is the primary responsibility of the CR to perform.

The primary parameter on which the CR use to sense the state of the radio is the gotten from the data it detect within the defined sensing environment. There have been some research works that focus on CR blind knowledge of the PU [11-12]. A common mathematical representation of the performance of the CR is to distinguish two mutually independent and identical Gaussian sequences.

$$\left.\begin{array}{c}\mathcal{H}_0{:}y(x)=\omega_{(k)}\\ \mathcal{H}_1{:}y(x)=h_{(k)}.S_{(k)}+\omega_{(k)}\end{array}\right\} \tag{1}$$

For $k = 1, \dots n$ where $\omega_{(k)}$ and $S_{(k)}$ are zero-mean complex Gaussian random variable with variance $\sigma^2_{(\omega)}$ and $\sigma^2_{(\omega)}$ per dimension. Let $y = [y_{(1)}, \dots, y_{(n)}]$ denote the vector of the n observed samples. We find it convenient to denote $\sigma^2 = \sigma^2_{(\omega)}$ and $\sigma^2 = \sigma^2_{(s)} + \sigma^2_{(\omega)}$. In practice systems there are two types of sensing systems, namely *Missed detection* which occurs when the CR interferes with the primary user channel in error thinking it is a spectrum hole, *False detection*: which result from an undetected hole, that is where a hole actually exist but the CR is not able to identify as hole and *Hit or truer detection*: where a hole exist and the CR is able to identify the hole as a hole in the spectrum.

B. *Resource Allocation*

The haemoglobin molecule is basically a loading protein consisting of four globin molecule and each accepting only a maximum of four O_2, each O_2 for a globin. If each globin is considered a sub channel N of the haem user K, and our objective is to optimize the subchannels and power allocation in order to achieve the highest sum error free capacity under the total power constraint.

We adapt the equal weighted sum capacity as objective function, but we introduce the idea of proportional fairness into the system by adding a set of nonlinear constraints. The benefit of introducing proportional fairness into the system is of nonlinear constraints. The benefit of introducing proportional fairness the system is that we can explicitly control the capacity radio among users and ensure that each user is able to meet his target data rate, given sufficient total available transmit power.

We therefore adapt the optimization problem formulated in [13]. Also study the suboptimal sub channel allocation given in described algorithm step (1)-(3).

II. PROPOSED ALGORITHM

In this research, the Haemoglobin Binding (HB) Algorithm. HB algorithm is motivated by how a protein in the erythrocyte red blood cell called haemoglobin behave. The haemoglobin carriage on which oxygen is carried from the alveoli in the lungs to other body tissues in other parts of the body. The haemoglobin is contained in the erythrocyte and any one not present in it is excreted by the kidney. The haemoglobin also perform other functions such as enzyme which catalize the reversible reaction between carbon dioxide and water to form carbonic acid and transport carbon dioxide in the tissues back to the lung alveoli, thus allowing for an exchange of gases in the body system.

Under normal condition, oxygen in the blood is carried primarily by haemoglobin which consist of four iron atoms for carrying four molecules of oxygen. Each of the oxygen molecule is loosely bounded to the haemoglobin atom and reversibly with the haem portion of the globin. The rate of binding and reversal is influenced by the pressure of the oxygen in that region of the body. Binding of oxygen to haemoglobin is favoured by high pressure as in the pulmonary capillaries, but where the partial pressure in a region is low, like in the tissues, oxygen in released from it. This simple mechanism serve as the basic principle for transporting oxygen around the body. It is known that the haemoglobin essentially transport 97% of oxygen present in systemic circulation, thus making it a very effective system for oxygen transportation. Since the haemoglobin molecule can only accommodate four molecules of oxygen, it is also intuitive to reason that the system has a very good sensing system in order not to overload the protein molecule. Another unique characteristic of the oxygen-haemoglobin binding system is that, it binds by using a reward system. The higher the number of globin molecules that are attached to an oxygen, the easier the next oxygen is able to bind to the unbounded globin molecule, thus making the binding system a reward system, such that it every haemoglobin in attempt to meet its full potential will always want to be open to binding. This unique quality of the haemoglobin has motivated choice as a suitable algorithm for cognitive radio network design.

The allocation will be done on the principle of water filling algorithm where resources in the sensed spectrum are allocated based on the state of the channel. In our algorithm, we propose that, provided the primary users and secondary users minimum tolerance is not exceeded, the allocation will be done based on the most busy band. This is a primary difference between our proposed methods of resource allocation from traditional water filling equalization technique where the busy channel is awarded less spectrum seekers. Just as in the haemoglobin binding, the saturation of the channel could be determined using the oxygen-haemoglobin dissociation curve and the affinity for each allocation increase the same way as shown in equations in ‘the reward system’ part of this work. It is also important to note that binding between the oxygen molecule and the haemoglobin occur reversibly until the channel becomes fully saturated. In the case of the oxygen-hemoglobin binding, when four molecules of oxygen are bounded to the haemoglobin molecule.

III. THE REWARD SYSTEM

The probability of oxygen molecule been attracted or attached to haemoglobin is proportional to the amount the oxygen molecule that have already been attached to it. Usually the higher the oxygen molecule that is bounded to the haemoglobin, the higher the likelihood that another oxygen will find the haemoglobin molecule and attach to it until the channel becomes fully saturated. The equation showing is relationship between haemoglobin and oxygen [14] is shown in the equation below:

$$Hb + O_2 \overset{k_1}{\leftrightarrow} HbO_2 \tag{2}$$

$$HbO_2 + O_2 \overset{k_2}{\leftrightarrow} HbO_4 \tag{3}$$

$$HbO_4 + O_2 \overset{k_3}{\leftrightarrow} HbO_6 \tag{4}$$

$$HbO_6 + O_2 \overset{k_4}{\leftrightarrow} HbO_8 \tag{5}$$

And the relationship for the association constant is given by

$$k_1 = \frac{[HbO_2]}{[Hb][O_2]} \tag{6}$$

$$k_2 = \frac{[HbO_4]}{[HbO_2][O_2]} = \frac{[HbO_4]}{k_1[Hb][O_2]^2} \tag{7}$$

$$k_3 = \frac{[HbO_6]}{[HbO_4][O_2]} = \frac{[HbO_6]}{k_1k_2[Hb][O_2]^3} \tag{8}$$

$$k_4 = \frac{[HbO_8]}{[HbO_6][O_2]} = \frac{[HbO_8]}{k_1k_2k_3[Hb][O_2]^4} \tag{9}$$

And therefore

$$K = k_1k_2k_3k_4 = \frac{[HbO_8]}{[Hb][O_2]^4} \tag{10}$$

Where K is the net association constant for the overall reversible reaction of the oxidation of Hb. For n number of oxygen association K will be given by

$$K_x = \frac{[HbO_n]}{[Hb][O_{n/4}]^{n/2}} \tag{11}$$

The analogy between the sensing and allocation scheme in CR using the hemoglobin and oxygen association and dissociation is given in the table below:

TABLE I. COMPARISON BETWEEN PARAMETERS IN BLOOD AND WIRELESS ENGIRONMENT

	Parameter in the Network	Equivalent in the Oxygen-Hem Molecule
Resource	Desired signal	Oxygen
Parameter to Be Sensed	Energy	Oxygen insufficiency
Noise	Disturbances within the wireless space	Differences in pressure and acid-base balance

For a given number of globin molecules, with each globin representing a particular sub Chanel, if the bandwidth of the sub channel is B, the approximate spectrum of the nth subchannel spans from the starting frequency (f_s) to the nth frequency band given as

$$f_s + (n-1)B \ to \ f_s + nB \tag{12}$$

Been that the pressure has a time rate of change relationship with energy as

$$Pressure = \frac{change\ in\ internal\ energy}{volume} \tag{13}$$

Knowledge of pressure could be viewed in the context of spectrum carrying energy in a particular spectrum band thus offering a fair knowledge of the occupancy of the suband. Even though waves and spectrum are not fluid, the relationship in fluid give an analogous similarity with another physical quantity parameter, called power which is given as

$$Power = \frac{Change\ in\ energy}{time} \tag{14}$$

Been that the activity of each band is determined by the energy of the band, and a change in energy in the band over a period of time determine the energy of each band.

When the cognitive radio transmit information over the nth subband with unit transmission power, the interference introduced to the jth subchannel in the subband of the lth PU is given in [Resource allocation of heterogeneous cognitive radio with imperfect spectrum sensing] as

$$I_{i,l}^{n} = \int_{(j-1)B-((n-1)/2)B}^{jB-((n-1)/2)B} g_{n,1} \emptyset(f) df \ \ (Check\ equation) \tag{15}$$

IV. SYSTEM DESIGN AND IMPLEMENTATION

The algorithm design is based on the re-enforced allocation of oxygen to haemoglobin. The entire radio spectrum is sensed assumed to consist of multiple channel and sub channels, just as oxygen does to identify the unbounded channels and the vacant channels in the network could be estimated using the any threshold technique designed in [16], [17].

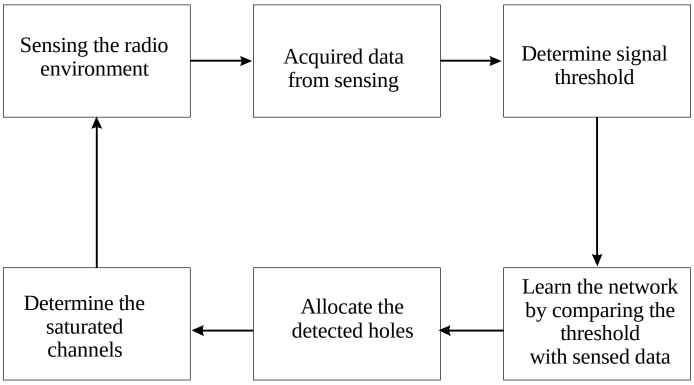

Figure 4. Spectrum sensing and allocation flow

If the sub channels consist of various discrete responses $h(l); l = 0, 1, \dots, L-1$, between the primary transmitter and a CR receiver with L denoting the number of solvable paths. The received front end is written as

$$r(n) = \sum_{l=0}^{L-1} h(l) s(n-1) + v(n) \tag{16}$$

Where $s(n) =$ is the primary transmitted signal with cyclic prefix at time n, $v(n) =$ is the additive complex white Gaussian noise with zero mean and $\sigma_v^2 =$ is the variance, $v(n) \sim \mathcal{CN}(0, \sigma_v^2)$. The discrete frequency response for the wideband band frequency selective fading environment through K points fast Fourier transform (FFT) for $K \geq L$ is given by

$$\mathrm{H_k} = \frac{1}{\sqrt{\mathrm{K}}} \sum_{\mathrm{n}=0}^{\mathrm{L}-1} \mathrm{h(n)} \mathrm{e}^{-\mathrm{j}2\pi \mathrm{nk/K}}, \quad \mathrm{k} = 1,2, \dots, \mathrm{K} \tag{17}$$

And the received signal in this discrete Fourier transform (DFT) is given by

$$R_k = \frac{1}{\sqrt{K}} \sum_{n=0}^{K-1} r(n) e^{-2\pi nk/K} \tag{18}$$

$$= H_k S_k + V_k \quad k = 1,2, \dots, K \tag{19}$$

Where S_k is the primary transmitted signal at subchannel k and the received noise in frequency domain is V_k given as

$$V_k = \frac{1}{\sqrt{K}} \sum_{n=0}^{K-1} v(n) e^{-2\pi nk/K}, k = 1,2, \dots, K \tag{20}$$

Equation 19 is similar same as equation 1 with parameters $H_k = h_k, S_k = S_{(k)}, V_k = \omega_{(k)}$.

The summary statistics of subbands k over a summary statistic of received signal intervals of M samples is given by

$$Y_k \triangleq \sum_{n=1}^{M} |R_k(n)|^2, \ k = 1,2, \dots, K \tag{21}$$

And the decision on the state of the channel, whether it is vacant or busy is given by $Y_k \underset{\mathcal{H}_{0,k}}{\overset{\mathcal{H}_{1,k}}{\gtrless}} \gamma_k \quad k = 1,2,\dots,K$, Where γ_k is the decision threshold of subchannel k. With $\mathcal{H}_{1,k}$ meaning the channel is busy and $\mathcal{H}_{0,k}$ meaning the channel only has noise in it.

In this work, we adapt the Otsu threshold technique, in [17], where the threshold is arranged to be adaptive to the quantization value of the measured data. Hence for a set of quantized values

$$Y_k = \{y_1, y_2 \dots y_K\}$$

The threshold is adaptively taken in sequence as

$$Y_k = \{\gamma_1, \gamma_2 \dots \gamma_K\}$$

Been that all resources in the wireless network occupy the same fixed resource, the wireless spectrum, however, the user will have various requirement at each point in time for this resources. The next paragraph is adapted from the fairness model in [a fairness model for resource allocation in wireless networks] with the only modification been in the condition for weight assignment where we considered percentage utilization of a channel instead of historical allocation information. From the analyzed samples of Y_k, we assume that number of vacancies in the spectrum are identified as Y_{P_i}. We also assume fairness in the network where there are $m(m \geq 1)$ different resources and the capacity of resource k is C_k^t for n individuals in the system. At time t, the allocation decision made is $\mathbb{X}^{(t)} = \left(X_1^{(t)}, \dots, X_n^{(t)}\right)$. Where $X_k^{(t)}$ is the allocation of resource k and $X_k^{(t)} = \left(x_{k1}^{(t)}, \dots, x_{kn}^{(t)}\right)$, $x_{ki}^{(t)}$ is the amount of resource k that is allocated to individual i. The capacity of a channel is given by

$$C = B(i) * \log_2(1 + SNR) \qquad (22)$$

For the allocation decision $\mathbb{X}^{(t)}$, the system fairness metric is given by $F_k^{(t)}\left(\mathbb{X}^{(t)}\right)$. And on the set of individual resources i the fairness metric for the resources for the given allocation decision is given by $f_{ki}^{(t)}\left(\mathbb{X}^{(t)}\right)$ where $f_{ki}^{(t)}$ is the fairness of individual resource i over resource k.

If the allocation decision for the resources is given by $\mathbb{X}^{(t)} = \left(x_1^{(t)}, \dots, x_n^{(t)}\right)$, one elements will be considered during the allocation the percentage of spectrum holes in the network. This is

For individuals with more requests and higher current channel utilization than others, heavier weights should be assigned to them, given them higher chance to obtain more resources. And hence higher revenue from the requesting radio (CR). We also assume that weights $\mathbb{W}^{(t)} = \{W_1^{(t)}, \dots, W_m^{(t)}\}$ and $W_k^{(t)} = \left\{w_{k1}^{(t)}, \dots, w_{km}^{(t)}\right\}$. In which $W_k^{(t)}$ is the weight of resource k and $w_{ki}^{(t)}$ is the weight of individual i for resource k at time t.

In order to encourage the PU to lease their subbands, each PU is rewarded for each leasing it makes. The PU with the highest request weight i.e. highest sensed energy will be noticed and rewarded with higher potential for the new spectrum seeker to locate them provided their channel capacity has not been exceeded or cause interference between the channel users. The weight of resource, $\mathbb{W}^{(t)}, W_1^{(t)}$ and $w_{k1}^{(t)}$ assigned to request $\mathbb{X}^{(t)}$, $X_k^{(t)}$ and $x_1^{(t)}$ is proportional to the weight of the resource. If the percentage occupancy of a hole increases, the weight of resource for successive assigned to the channel also increases.

V. RESULT AND ANALYSIS

A set of data was collected to give the following graph

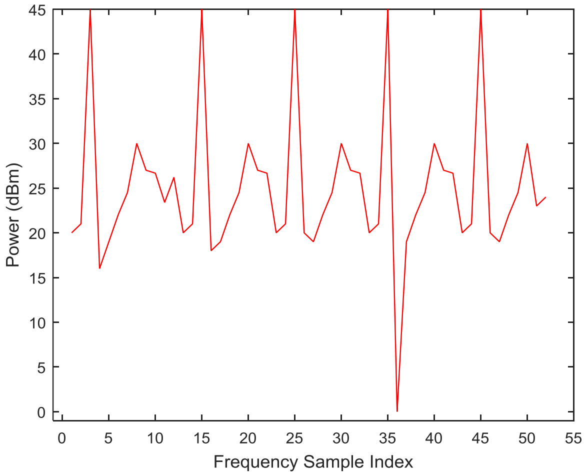

Figure 5. Absolute value of measured data

For the set of positive detection and false detection, a combine plot was made along with the measured data as

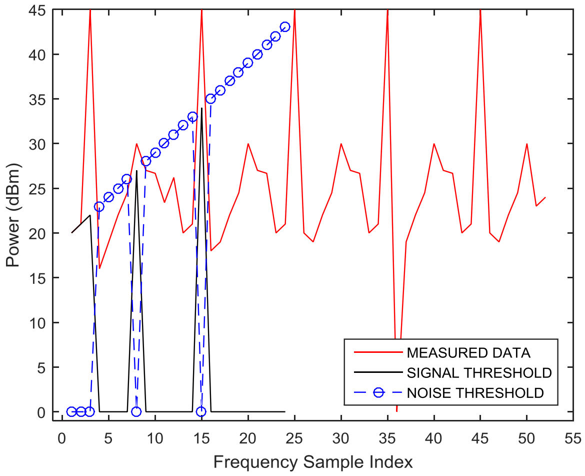

Figure 6. Measured data on signal and noise threshold

The break in the threshold values of noise and signal threshold is accounted for by the quantization losses. Allocation will be done to channels with a noise detection only, that is a channel represented by $\boldsymbol{\mathcal{H}_0}$ in equation 1.

The allocation can only however will be done by first allocating resources fairly to all channels and subsequently, to the channel with the channel with the highest channel saturation capacity. This will be done with the assumption that the association rate for the channel with the highest capacity increase after every increased allocation.

VI. CONCLUSION

This work lay the framework for a new cognitive radio framework with the primary aim of increasing of encouraging licensed spectrum operators to increase their willingness to their spectrum. This allocation framework also has benefit for the leasing radio user in that it will encourage increased revenue for the PU who leases out more of its spectrum. In the work, Otsu threshold technique is used to determine the spectrum holes in the sensed data and a plot of the signal and noise threshold is developed for increasing threshold.

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