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Original Article

A Novel Dynamically Sensing and Resource Allocation in a Cognitive Radio Network using Inspiration from Hemoglobin Binding Algorithm

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Abstract - *The eminent challenge on today's radio spectrum is caused by the mode of spectrum allocation that is currently being adapted by spectrum regulators. It is, therefore very, essential that this allocation policy be broken to allow radios equipped with good cognition of the spectrum space to take advantage of the spectrum space and allocate their spectrum under the right condition. This paper proposes a dynamic allocation system based on oxygen-haemoglobin detection and allocation system where preference for allocation is given to spectrum holes with higher allocation over those with lower allocation. The primary motivation for the algorithm is to reward channel(s) spectrum users who are most willing to lease their channels, thus motivating more primary users to open up their spectrum for secondary users. In the work, a mathematical framework for computing spectrum holes has been presented, data has been used to determine this, and the allocation process is performed based on the proposed method.*

Keywords **-** *Spectrum allocation, Oxygen-haemoglobin detection, Cognition, Spectrum holes, Primary user, secondary user.*

1. Introduction

Today's wireless networks are characterized by a static spectrum assignment policy [1]. However, with increasing spectrum demand recently, this static policy seems not to be an impressive method of allocating spectrum anymore as the available spectrum is a fixed resource and the available spectrum is almost already fully allocated, posing a threat to hurt innovation that requires new spectrum allocation.

However, it has been observed from several spectrum campaigns around different locations, as reported in [2] and [3], that most of the assigned spectrum is only used sporadically, as it is most time idle or grossly underutilized.

Unfortunately, since the contemporary spectrum allocation scheme as defined by the world spectrum regulatory body, the International Telecommunication Union (ITU) does not support open access to some spectrum at any time and the absence of hardware to intelligently find and make use of this spectrum without causing harm to the licensed user. This idea of intelligent use of spectrum by unlicensed users without causing harm to the licensed user is based on the principle first proposed by Joseph Mitola in his 1995 paper [4]. Radios equipped with this intelligence are called cognitive radios (CRs). The cognitive radio is an unlicensed user, also called a secondary user. The licensed user is also called the primary user. There is a need to develop a dynamic spectrum vacancy awareness system. The In-operation of a fair allocation system has inspired this research work. The work also hopes to provide an efficient method for exploiting the wireless spectrum optimally and in an orderly manner.

To achieve the aim of this research, we studied the behaviour of haemoglobin, an iron-containing substance in the red blood cell that serves the function of transporting oxygen from the lungs to other parts of the body during external respiration. Hemoglobin performs this function with very high efficiency. It is reported in several pieces of literature that over 95% of oxygen in the systemic circulation is carried by Haemoglobin (Hb).

Haemoglobin carries oxygen from the lungs and releases the same in the tissues with the influence of external factors such as blood pressure, temperature, 2,3-BPG, availability of oxygen and deoxygenated hemoglobin, among several other factors. During the allocation of oxygen to the deoxygenated hemoglobin chain, it is usually more difficult to allocate oxygen to a completely deoxygenated hemoglobin molecule than to those that still have an oxygen atom attached to them. The difficulty continues to reduce for every newly attached oxygen until the hemoglobin molecule becomes fully saturated. Chapter 41 of [5] serves as a good reference resource on how oxygen-hemoglobin binding occurs. The allocation of oxygen atoms to hemoglobin is a natural and adaptive process based on a pressure gradient. According to

Dalton's law of diffusion, molecules will naturally flow passively from a region of high concentration to areas of low concentration. In a similar manner, CRs will naturally flow into empty channels in the network. The adaptation is made by the ability of the haemoglobin (channels) in the network to alter their shape to accommodate more CR needs.

To the best of our knowledge, our proposed algorithm in this work has never been proposed in any research work as a solution in CR networks (CRN). Unlike several other algorithms proposed in the past, the algorithm operates a dynamic sensing and resource allocation system where allocation is done based on knowledge of the channel and surrounding channels. That is, identifying and allocating resources to a good channel is not made exclusive of the performance of neighbouring channels. Their performance is constantly monitored and rewarded appropriately. The challenges of CRN will be addressed in this work by offering cognitive radio and an easy methodology to find available frequency bands by sensing the channel with the largest percentage occupancy. This is done by taking the frequency bands in the network with the band with the highest occupancy (saturation level). This will have the most obvious tag, which the band's energy will determine. Admission of a new cognitive user channel into the proposed network does not motivate the ejection of an older user in the network. The primary user has the key to eject any secondary user. However, the ejection is done fairly, based on the CR revenue to the network.

2. Literature Review

There exist several algorithms that have been used in the past to address the problem of spectrum shortage in the context of the cognitive radio network. For example is the water-filling technique [6], where resources are allocated to a channel in an equalization fashion until all the channels in the band become utilized to their full capacity. The water-filling technique, as it has been used, has several demerits because of its lack of dynamics or temporary blindness to the potential of neighbouring channels in the network till the potential of one channel has been fully utilized.

Another popular algorithm in use is the evolutionary algorithm. This algorithm is a bio-inspired algorithm based on the Darwinian concept of evolution. It is a population-based concept, and it has widely been used in several pieces of literature as a fine solution to spectrum sensing and allocation problems because of its good approximation ability when solving computational problems. Arguably the most common bio-inspired or related technique that has been used in literature in CRN is the genetic algorithm; however, they also exist several other techniques that are widely in use in cognitive radio, such as the swarm algorithms [7-9] other bio-inspired algorithms that have been used to address the challenge of CRN are firefly algorithm, harmony search, wolf path search among several other techniques.

They also exist several statistical techniques that have been used in CRN applications, such as Monte Carlos or the Las Vegas technique. Two fundamental factors that define a CRN’s efficiency in all applications are spectrum sensing and resource allocation. Spectrum sensing is one of the fundamental functions of a CR, and it is a key determinant of the efficiency of cognitive radio. It has been studied in many pieces of literature [10-11].

Its principle of operation is basic. It serves to detect the presence or absence of the transmission activity in a channel to know. If the spectrum band is currently occupied (active state), the CR is not allowed to transmit, and when the channel is (idle) indicating a hole, the CR is allowed to transmit. These two radio states could be described as a binary operation where an active state is described as one (1) state of the sensor, and an idle state is described as a zero (0) state of the sensor.

There are several methods of spectrum sensing, with the most common ones being *energy detection*, which has been studied in [12-14]*; matched detection*, which has been studied in [15-16] *and cyclostationary detection*, which has been studied in [17-18]. The sensing parameters depend on the type of sensing technique adopted. In general, however, the parameters that could be sensed in the network include but are not limited to the following; transmission power, interference temperature, transmitted signal, activities in the channel, and duration of the transmission.

Resource allocation (RA) in communication has gained a lot of research attention, as can be seen in the volume of published kinds of literature on the topic; for instance, works like [19] used a mathematical optimization approach to address resource allocation using physical topology bandwidth and time, [20] used Radio Environment Maps to predict channel performance like channel capacity, spectral efficiency and secondary network throughput using a centralized network and how it can be used to perform a multi-channel multi-hop routing in a distributed Dynamic Spectrum Access (DSA) network and [21] who worked to increasing throughput of data flow as well as maintaining fairness between the network users using mixed programming solution.

Resources allocation could be categorized as a layered approach problem based on the different layers of the International Standards Organization (OSI) model (Application, presentation, session, transport, network, network, data link and physical) layer or earlier Transmission Control Protocol/ Internetworking Protocol (TCP/IP) suite (physical, data link, network, transport and application) layer depending on the nature of resources. An overview of how to solve resource allocation on the different levels has been addressed in [22-23].

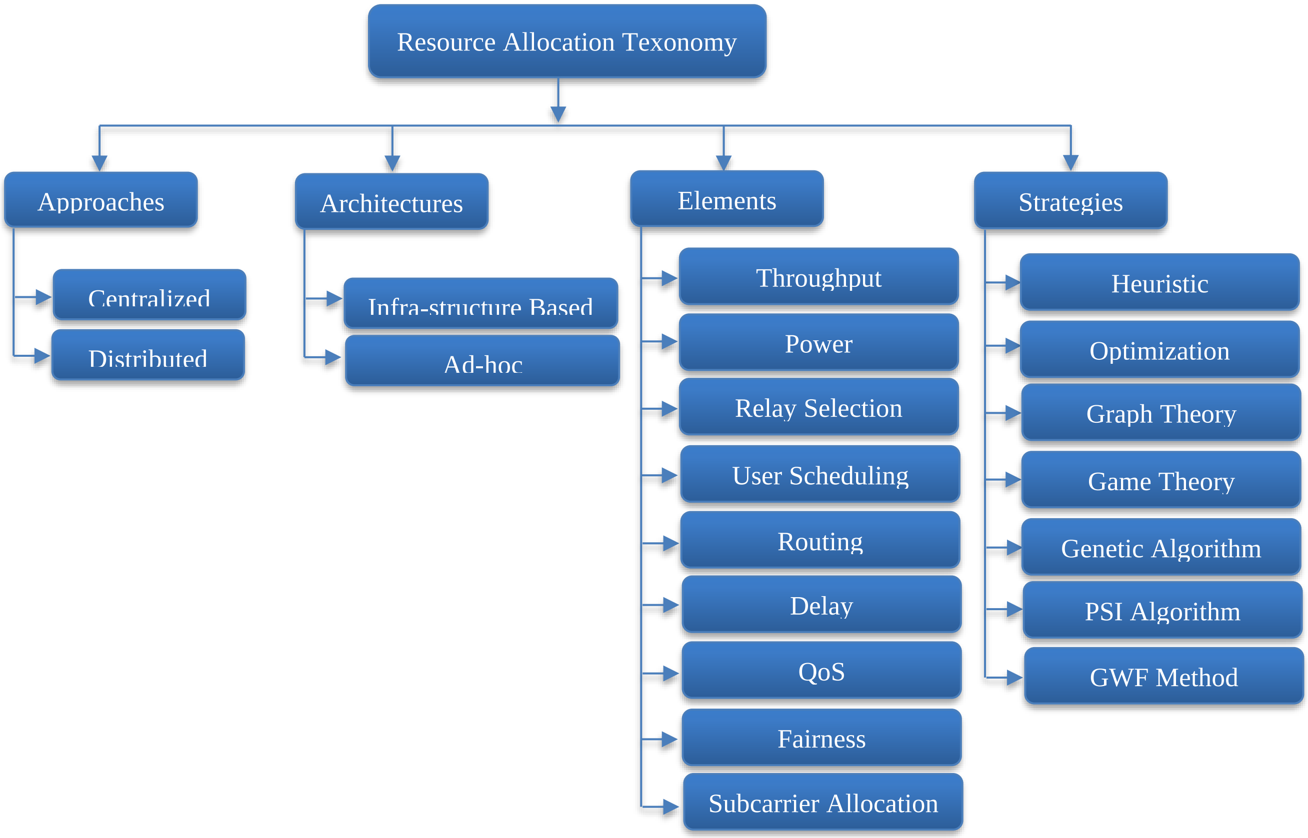

Fig. 1 Taxonomy for the resource allocation in CRNs

The study of resource allocation in our CR will, however, not involve the study of these individual layers in isolation. Although much of this research has been outside the context of cognitive systems, as could be seen, it must be noted that the methods used in these works have significantly inspired this works in resource allocation in cognitive radio networks. There has also been a significant amount of literature that bother cognitive radio network [24-27]

Resource allocation in a CRN can be categorized into several classes based on the approaches to which it is implemented. These approaches could be based on the architecture of the nodes and elements used for making the decision. These approaches are summarized in Figure 1 as copied from [28]. Resource allocation could also operate either in a cooperative manner where the nodes in the network work to share information and support one another, or it could operate in a non-cooperative form where cooperation does not exist between the nodes in the network; rather transmitting with understanding with another node it simply works with the receiving node as independent units from any other link that exists in the network.

Events in the real world are so large, complex and interdependent that it is sometimes impossible to find real-world problems and solve them efficiently [29]. However, finding a solution to the network problems is important anyway. To do so, a tradeoff is usually adopted between the various objective functions for the system's efficiency. This solution is called the optimal solution.

Correct Mathematical models are essential to solving optimization problems as it is a basic step towards attaining a balance between the system's variables. Optimization problems search to find the best solution to a problem by developing an organized framework for the cognitive network. The network aims at selectively building a network.

3. Proposed Algorithm

Our proposed solution is inspired by the oxygen-hemoglobin association and dissociation, a concept used in medicine to describe the binding of oxygen to haemoglobin molecules in the red blood cell.

To ease the workload on the resource side, the energy level of each vacant channel is proportional to the unused bandwidth capacity of the channel. The network operator, therefore, arranges the vacant channel based on how generous the radio user is in leasing out its available channel. It does this by calculating the percentage capacity occupancy as

$$Percentage\ capacity\ occupancy\ (\%) = \frac{Occupied\ space}{-available\ space} \quad (1)$$

Our analogy between the sensing and allocation scheme in CR using the hemoglobin and oxygen association and dissociation is given in Table 1 below.

Table 1. Comparison between parameters in blood and wireless environment

	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.

The sensing and allocation decision will be made using the following adaptive cognitive algorithm.

1. The received signal is analyzed to identify the holes in the spectrum.
2. The decision on whether a channel is a hole or not is made by comparing the signal with the threshold value.

If

a) The detected signal is greater than or equal to the noise threshold level, and then the primary user is present

$$Signal \geq Threshold\ level$$

b) otherwise, the channel is vacant

$$Signal < Thresholdlevel$$

3. The probability of picking a vacant channel is equal to the first allocation of the channel. But for subsequent channels, the allocation is done proportional to how saturated the leased channel is. The channel with the most percentage saturation channel is allocated before the one with the least percentage saturation defined in Equation 1.

3.1. Spectrum Sensing

The framework for sensing is basic. This is done by characterizing the activity of the spectrum into threshold or quantized values. Then the band which meets the specified signal quality of service is selected and classified as either vacant or busy. The figure below shows the spectrum sensing mechanism. It shows the relationship between the environment and used and unused channels in the spectrum band with the cognitive engine at the centre to make the decision of which channel is free and which is not. The mathematical relationship between the vacant and used channels in the environment is given in section IV.

$$\left.\begin{array}{c} H_0: y(t) = w(t)\text{Noiseonly(Vacantchannel)} \\ H_1: y(t) = h.x(t) + w(t)\text{Signal + Noise(Channelnotvacant)} \end{array}\right\} \quad (2)$$

3.2. Resource Allocation

Our resource system will be viewed as a reward system where the reward amount is proportional to the primary user's willingness to lease its bandwidth. The PU that offers to lend its bandwidth more is more likely to be noticed by new spectrum seekers. This, therefore, motivates the licensed user to lease their bandwidths.

We model the system with the knowledge that the intensity of haemoglobin molecules varies from molecule to molecule. A molecule with higher oxygen atoms attached to it below its maximum capacity will be noticed by more oxygen than the one which has more oxygen molecules. Using this analogy, therefore, the PU will always want to

Release its unused band to spectrum seekers to attract revenue.

The CR senses this unused band using an energy flag that the primary user sends out, just like oxygen recognizes and notices the unused haemoglobin molecule based on the intensity of attraction to the unbounded oxygen molecule.

The CR senses the energy radiated or the intensity of the flag given by the channel willing to be leased.

For a set of $Y_{(m)}$ channels, the secondary user senses the unused channels and arranges their probability of being used in increasing order as

$$Y_{(m)} = \{y_{(1)}, y_{(1)} + q, y_{(1)} + 2q, \ldots, y_{(1)} + (M-1)q\}$$

Where the intensity of the most flagged channel is $y_{(1)}$ and q is the step factor of the sensed signals.

4. System Implementation

Otsu threshold algorithm will be used to compute the vacancies of the channels in the environment by autonomous adjustment of environmental signal to adapt to a computed threshold of the sensed signal to avoid interference with the transmitting radio. The threshold for the signal determines the performance measurement values for the probability of detection (P_d) false alarm (P_f).

For a received signal $y(t)$, the antenna input is typically modelled as equation 2. As restated here,

$$H_0: y(t) = w(t); for\ t = 1,2, \ldots, N$$

$$H_1: y(t) = h(t).s(t) + w(t); for\ t = 1,2, \ldots, N$$

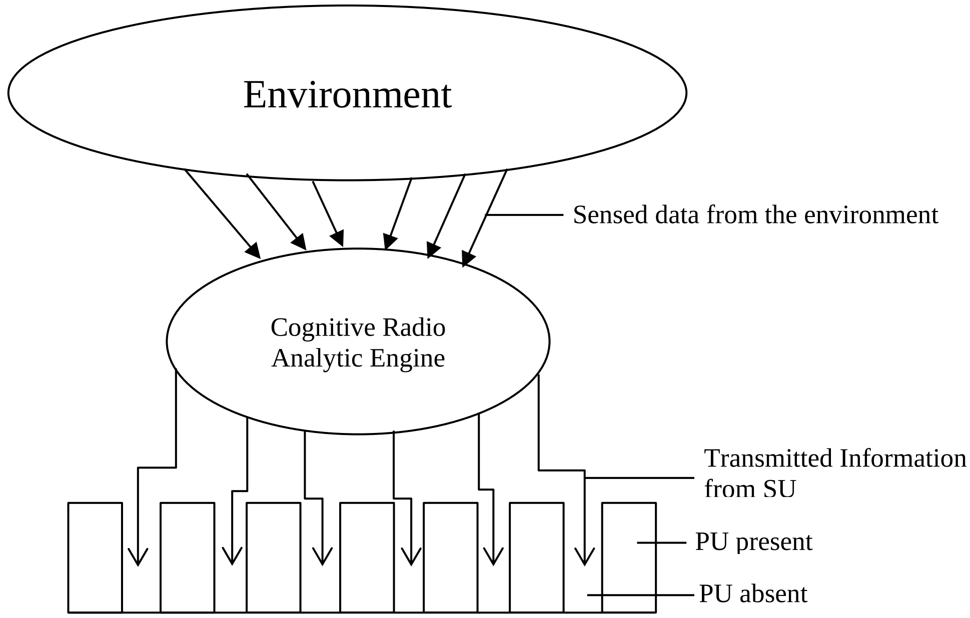

Fig. 2 Sensing mechanism

Where; t is the time index, $h(t)$ is the channel impulse response, $s(t)$ is the transmitted signal, $w(t)$ is the ambient/ system noise modelled as Additive White Gaussian Noise (AWGN), and $*$ symbol denote the convolution operator. N is the ceiling function of the product of the total sensing period (T_s) and sampling frequency (f_s). H_0 and H_1 are the hypothesis that describes the case where the received signal comprises elements of a noise-only sample and a case where the received signal comprises elements of signal plus noise ratio.

For a frequency channel, the channel is usually studied using the fast Fourier transform (FFT) algorithm where $y(t) = Y(f)$ and $w(t) = W(f)$. N is recomputed in the frequency domain as $\boldsymbol{F}$ was given as

$$F = 2^{\lceil \log_2(T_s \times f_s) - 1 \rceil} \tag{3}$$

The sensed/received samples, which refer to a frequency channel, are fed to a self-adaptive threshold adjustment block where processing takes place to compute a suitable threshold value γ. Each channel of $Y(f)$ is compared to γ to determine the state of off.

The decision of which channel is completely a noise channel or a channel with signal and noise is then determined by comparing the input sample against the determined threshold.

If $Y(f) < \gamma$, then the channel is only occupied by noise only; hence the channel is free and

If $Y(f) \geq \gamma$, then the channel has both signal and noise. Hence the channel is not free for use by cognitive radio.

Using the non-parametric amplitude quantization method defined in [Amplitude quantization method for autonomous threshold estimation in self-reconfigurable cognitive radio systems], the quantization level M is given by

$$M = \left\lceil 1 + \log_2 F + \log_2\left(1 + \frac{|g|}{\sigma_g}\right) \right\rceil \tag{4}$$

Where $|.|$ is the modulus function and $\lceil . \rceil$ is the ceiling function. g is the estimated 3rd moment (skewness) of the distribution obtained as

$$g = \frac{\frac{1}{F}\sum_{i=1}^{F}\left(Y_i - \overline{Y_f}\right)^3}{\left(\frac{1}{F}\sum_{i=1}^{F}\left(Y_i - \overline{Y_f}\right)^2\right)^{\frac{3}{2}}} \tag{5}$$

Where $\overline{\quad}_{If}$ denotes the mean of the input sample set Y_f and variance σ_g

$$\sigma_g = \sqrt{\frac{6(F-2)}{(F+1)(F+3)}} \tag{6}$$

The quantization step size q for Y_f is calculated as

$$q = \left\lceil \frac{y_{(F)} - y_{(1)}}{M} \right\rceil \tag{7}$$

From the result of $Y_{(f)} < \gamma$ and $Y_{(f)} \geq \gamma$, the computed values are shown in Tables 2 – 5.

The outcome from the vacant channels is modelled for a set of bandwidth capacities using the formula.

$$C = B(i) * \log_2(1 + SNR) \qquad (8)$$

As stated earlier, the respiratory algorithm is applied by assigning rewards to the percentage of occupancy of the channel capacity. The channel with the highest occupancy level will be assigned higher radio demands than those with lower occupancy. This is done with the assumption that the same transmit and received power is obtainable in the antennas. The rationale behind assigning these weights is to encourage the licensed user to open up its band for cognitive users in exchange for revenue the cognitive user will pay it. Simulation of the channel capacity is done for bandwidth in Hz 1, 20,50,100, and SNR in dB 0, 5, 10, 15, 20, 25, and 30 is presented in the result section.

For simplicity, the capacity C is computed as a ceiling function ($\lceil C \rceil$).

5. Result

5.1. Sensing

After computing the equations stated above, the input data set in Appendix A is given in Table 2 – 5.

Table 2. Computed parameters from the Otsu threshold technique

Parameter	Symbol	Value
Sensed data in the frequency domain	F	32768
Total number of samples	m	90
Sampling frequency	F_s	4978
Probability of signal detection	P_s	0.9975
Probability of noise detection	P_w	0.0024
Ceiling function for the quantization step	q	4

Table 3. Computed signal threshold

4	8	12	16	20	24	28	32	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0							

Table 4. Computed noise threshold

0	0	0	0	0	0	0	0	36	40	44	48
52	56	60	64	68	72	76	80	84	88	92	96
100	104	108	112	116	120	124	128	132	136	140	144
148	152	156	160	164	168	172	176	180	184	188	192
196	200	204	208	212	216	220	224	228	232	236	240
244	248	252	256	260	264	268	272	276	280	284	288
292	296	300	304	308	312	316	320	324	328	332	336
340	344	348	352	356							

5.2. Allocation

For a set of generated values for the channel capacity

Table 5. Sequence of bandwidth allocation

100	206	346	503	666	831	997

We simulate the random demands by network users using the =RANDBETWEEN() function in excel for the first seven holes for the allocation requests set to generate values from zero to the maximum channel capacity for each channel. Moreover, after each random set of random requests, the cognitive radio determines a preferred licensed channel to approach during frequency demand based on percentage occupancy from the energy strength it receives from the set of channels. A channel that has a higher percentage of occupancy will emit higher energy than the one with a lower energy level.

Every user generates the same amount of energy for the first set of generated requests. Hence the CR senses every band as having the same capacity except after the first attempted allocation. We assume that the primary user channel has the ability to increase its energy without an as long as the channel capacity is not reached.

The preferred allocation sequence is sequentially arranged based on the occupancy level, as shown in Table 6 below.

Table 6. Allocation of spectrum holes based on the proposed algorithm

		FIRST ALLOCATION					
S/N	Bands	Quantity of request	Percentage Occupancy (PO)	Position based on (PO)	Used bands	Unused bandwidths	
1	100	75	75	2nd	75	25	
2	206	80	38.835	6th	80	126	
3	346	119	34.3931	7th	119	227	
4	503	290	57.6541	4th	290	213	
5	666	391	58.7087	3rd	391	275	
6	831	652	78.4597	1st	652	179	
7	997	543	54.4634	5th	543	454	
		SECOND ALLOCATION					
S/N	Bands	Quantity of request	Percentage Occupancy (PO)	Position based on PO	Used bands	Unused bandwidths	
1	100	99	99	1st	99	1	
2	206	80	38.835	6th	80	126	
3	346	119	34.3931	7th	119	227	
4	503	290	57.6541	5th	290	213	
5	666	472	70.8709	4rd	472	194	
6	831	822	98.917	2nd	822	9	
7	997	985	98.7964	3rd	985	12	
		THIRD ALLOCATION					
S/N	Bands	Quantity of request	Percentage Occupancy (PO)	Position based on PO	Used bands	Unused bandwidths	
1	100	99	99	1st	99	1	
2	206	80	38.835	6th	80	126	
3	346	119	34.3931	7th	119	227	
4	503	290	57.6541	5th	290	213	
5	666	644	96.6967	4th	644	22	
6	831	826	99.3983	3rd	826	5	
7	997	987	98.997	2nd	987	10	

6. Conclusion

The designed system will perform optimally and reduce the time usually involved in determining which channel should be allocated a resource as the system perform both the sensing and allocation as a batch process. It is also our opinion that unlike earlier literature, where sensing and allocation is usually a trial and error process where at the end, there is usually a lot of collision and loss of data, this system of allocation eliminates the likelihood of a channel being allocated beyond its capacity and been that allocation is performed with prior knowledge, it is less likely that allocated data will collide with other cognitive users.

That adaptation is a hallmark of a good CRN design. The nodes in the elements can quickly change their character to avoid interference with other nodes during transmission. They can differentiate which channel is carrying a useful signal, in which case it will not use it and which is not.

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