CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Electronic wireless communication is transmitted with the use of Electromagnetic Frequency Spectrum (Goldsmith, 2006). It is a unique natural resource shared by various types of services which is free from depletion but subject to congestion through use. It has facilitated a sequence of revolutions in human communication. Although, if left unplanned, spectrum congestion can lead to harmful interference and hinder users from getting the best these services have to offer. Traditionally, spectrum band is allocated relatively over a long period of time for the use of a license operator. The use of radio spectrum in each country is nationally regulated by assigned government agency which is responsible for allocating spectrum bands to operators. In Nigeria, the Nigerian Communications Commission (NCC) is responsible for allocation of spectrum. This approach is termed the Fixed Spectrum Allocation (FSA) scheme. With this, the radio spectrum is split into bands and allocated on absolute basis to distinct technology based services, e.g. mobile telephony, radio and TV broadcast services.

Different spectrum bands offer different physical characteristics. Higher frequencies do not carry signals as far and do not penetrate buildings as easily, and lower frequencies have capacity limitations and create more interference. The UHF spectrum is particularly attractive because it is located between 200 MHz and 1 GHz offering an optimal balance between transmission capacity and distance coverage (COM, 2007). New services competing for the VHF and UHF band include mobile television, digital television, and wireless broadband and enhanced phone services.

Following the roll out of commercial mobile communication networks in many parts of the world, the radio frequency is becoming more valuable than ever. Individuals, businesses and governments rely on this natural resource for communication. The growth of Internet as a standard communication platform fueled the emergence of new services like wireless Internet access. As more devices are competing for wireless access, the available radio spectrum is becoming congested. The reserve radio resource pool is also depleting. Hence, in the future new allocations will inevitably become impossible, risking the growth of the whole wireless ecosystem come to a halt. The need to accommodate an ever-increasing number of users and offer bandwidth-rich applications using a limited spectrum challenges the system designer to continuously search for solutions that use the spectrum more efficiently. One technology that has successfully met this need is the digital television technology. The conversion from analogue to digital television will enable a country to benefit from increased spectrum efficiency since less bandwidth capacity is needed to provide the same television services compared to the analogue television.

Radio spectrum is the lifeblood of all wireless communications. Since early 20th century when large-scale commercial use of radio spectrum started, utilization of wireless is a significant factor in many economies around the world. Its contribution has been amplified with the advent of mobile communications in latter part of 20th century due to proliferation of mobile Internet and smart devices in the last few years. New access technologies and increased device capabilities in recent years have resulted in an exponential surge in demand for wireless data communications. This explosive demand has in many cases led to network congestion and the wireless industry is developing means to mitigate the problem through implementation of new techniques supplementing any additional exclusive spectrum.

In this dissertation the TV white space is explored as a solution to surmount the aforementioned problems. TV White Spaces refers the unoccupied portions of spectrum in the UHF/VHF terrestrial television frequency bands. The concept of sharing the highly valued UHF spectrum resource and its use with the primary terrestrial television service is a primary concern today. Wireless broad-band applications are the main focus of trials, nonetheless, the usefulness of this highly sought after spectrum is also being considered for other applications, such as machine-to-machine communications (M2M). TV White Spaces (TVWS) spectrum is a secondary spectrum technology that can take advantage of unused television spectrum in a dynamic manner.

In the developed countries, a process known as Digital Switch Over (DSO) has been completed that basically vacates the UHF and VHF bands as they have started TV broadcasting in Digital band.

In Nigeria, the VHF and UHF frequency bands are mainly occupied by television services. Presently, television broadcasting is analogue however; the government has began the process of DSO. In 2016 December to precise, the digital transition was tested in Abuja, Nigeria capital and the government promised to complete transition in other states before the deadline date. Transition to digital means spectrum can be used more efficiently and this also implies that some bandwidth can be released for new services. The released spectrum is known as the “digital dividend”. The digital dividend is a unique opportunity to meet the fast growing demand for wireless communication services. However, its benefit can only be fully reaped if proper planning is made, ahead of time, for the use of the released spectrum.

However, there is a great deal of underutilized bandwidth that can be found in the digital terrestrial television. A valuable chunk of this spectrum is allocated to television broadcasting which is particularly underutilized. When TV stations are allocated, the FCC intentionally spreads them out and puts blank channels in between stations in any geographic area to prevent adjacent channel interference between these high-powered broadcast transmitters. These blank channels are referred to as White Space.

The unused portions of the UHF spectrum, popularly referred to as white spaces, represent a new frontier for wireless networks, offering the potential for substantial bandwidth and long transmission ranges. These white spaces include, but are not limited to, 312 MHz of available bandwidth from channel 21 (474 MHz) to 70 (866 MHz), with the exception of channel 52, 53, 59 and 60 marked as reserved in Nigeria.

Subsequently, Akyildiz et al.(2006) found that spectrum use is intense on certain portions while a significant amount remains underutilized. High utilization is common in the cellular and frequency modulation (FM) radio bands, while other bands indicate low usage levels. Though, most of the license owners do not transmit all the time in all geographic locations where the license covers. Records from the FCC indicate that spectrum allocated in the bands below 3GHz have a utilization range of 15% to 85% (Smitha and Vinod, 2012). The current fixed spectrum management approach is therefore, inefficient since it leaves many portions on it unutilized and creates artificial shortage. New and more efficient management techniques are needed to make use of these free portions of the spectrum, also known as “spectrum holes” or “white spaces.” The development of new bandwidth demanding wireless technologies would depend on the availability of radio spectrum. As spectral resources become more limited, the agencies recommend that significant efficiency can be realized by deploying wireless devices that coexist with primary users. As a result, Dynamic Spectrum Access (DSA) was proposed to solve the inefficiency caused by the static allocation of spectrum as affirmed by (Mitola and Maguire, 1999). The basic idea of DSA is to allow frequency bands that are not being used by their licensed users, (also known as Primary Users (PUs)), to be utilized by cognitive radios CRs, (Secondary Users (SUs)) as long as they do not cause any harmful interference to PUs. Thus the secondary users take advantage of the available resources with minimal interference to the primary users. Consequently, groundbreaking techniques that provide new ways of exploiting the available spectrum are required. With this concept, use of existing radio spectrum is enhanced by opportunistic spectrum access (OSA) of the frequency bands that are not occupied by the licensed or primary user.

The report made by International Telecommunication Union (ITU) shows that the progress made in digital technologies has permitted the evolution of terrestrial television, making it more spectrally efficient by allowing, through digital compression techniques, the transmission of multiple high-quality TV programmes in one single spectrum channel (where before it was possible to transmit only one programme per channel with analogue TV) (Gomez, 2013). Such advancement resulted in the opportunity to reallocate new available UHF frequencies as a result of the analogue TV to digital TV transition (the Digital Dividend) for other uses, namely by wireless broadband applications, in response to the rapidly growing demand for mobile bandwidth.

Broadband internet access has become an essential element of modern life and a critical enabling agent for the global information age economy. In order to tap into the evolving means of lifestyle and source new means of livelihood in a global village, ubiquitous and affordable access to broadband internet service is critical. In Nigeria, according to Nigerian National Broadband Plan (2013-2018), there is appreciable number of submarine cable landings on the shores of the country providing over 9Tbits/s of combined capacity. However, there are concerns about the fact that all the landings are cited Lagos and as such access to other parts of the country is choked due to the limitations of distribution infrastructure to the rest of the country. Some of the challenges to the roll-out of effective broadband to the coastal and hinterland regions of Nigeria include the geographical topology and economic implications. As a result, most operators usually shy away from providing broadband in rural areas, leading to underserved and unserved regions. Thus there is the need to invest in alternative technologies which could complement coverage range with adequate downlink capacity. Among the promising solutions for extending broadband reach into unserved and/or underserved areas is an emerging networking approach known as TV White Space (TVWS). The term TV White Spaces usually refers to unoccupied portions of spectrum in the VHF/UHF terrestrial television frequency bands in some geographical areas (Gomez, 2013). This portion of the spectrum uses unlicensed, VHF/UHF TV channels to enable the transmission of internet traffic wirelessly over long distances.

These White Spaces vary in number of unused channels as a function of location, due to usage by licensed and unlicensed uses such as terrestrial analogue television broadcasting, Digital Television Broadcasting (DTB) and Program Making and Special Events (PMSE) uses. The spectrum range which includes (European range is 470-790MHz) are notable for their propagation qualities. TV White Space spectrum has the ability to broadcast signals over long distances. It permits more expansive reach than conventional Wi-Fi networks, which utilize higher frequencies that limit their range at a fixed power level. A typical outdoor Wi-Fi signal travels about 100metres versus TV White Space signals that may extend to 400metres at the same power level, or up to as far as 10km at higher power. This impressive reach has spawned the nickname “Super Wi-Fi” for TV White Space networks.

In addition to their impressive range, VHF and UHF frequencies are able to convey energy through physical obstacles. This is because radio signals traversing these frequencies has longer wavelength which has an ability to penetrate walls and buildings with lesser attenuation. These propagation characteristics allow TV White Space enabled broadband access networks to connect over long distances without line-of-sight restrictions, and/or to enable very fast internet connectivity over short distances and through physical obstacles.

As a result of these core basic characteristics – superior range and physical penetration coupled with unlicensed access to spectrum – the economics of TV White Space networks become attractive. There is no direct cost required to use or acquire unlicensed White Space spectrum, the cost associated with TV White Space as an internet delivery medium is instead mainly tied to developing technologies such as antenna and radios that make use of TV White Space. This, just like Wi-Fi can lead to rapid technological innovations tied to the use of TV White Space which can result to cheaper microchips and even technological cost.

Thanki (2014), posited that TV White Space spectrum has the potential to be the world's first globally available, broadband – capable licensed exempt band in the optimal sub – 1GHz spectrum. In unconnected urban and rural areas, entrepreneurs could use inexpensive, but reliable, Wi-Fi and other types of radio equipment capable of operating on TV band white spaces spectrum to deliver cost-effective broad-band services.

Cognitive Radio (CR) technology has emerged as the key solution to overcome the increasing need of spectrum for wireless communications (3G and 4G cellular system, Wireless Fidelity (WiFi), and Internet, through the implementation of the Opportunistic Spectrum Sharing (OSS) paradigm. It has become the enabling technology for the next generation (xG) network. Cognitive radio (CR) is an intelligent wireless communication system that is aware of its surrounding environment and under a certain methodology is able to use the current available spectrum momentarily without interfering with the primary user who paid to be served in that area (Mitola, 1999). For instance, let us imagine a portable radio that is able to communicate to its base which is relatively in proximity. This pair can be seen as secondary system and can be pictured as relative local service. Now assume the system is working at the same spectrum of the cellular phone system, which is the primary system; The secondary system should work in a kind of opportunistic way to borrow spectrum without interfering with the primary users or degrading the quality of its service. It therefore means that Cognitive Radio System should be able to scan and sense the spectrum around and find any available spot in frequency to establish its communication, that has to be released once a primary user comes back to claim the spot. Hence, it can be deduce that CR is an intelligent radio platform saddled with the ability to exploit its environment to increase spectral efficiency and capacity (Maninder et al.2012). CR's are regarded as transceivers that automatically detect (sense the existence of) available channels in a wireless spectrum and accordingly, change their transmission or reception parameters (Naroa, 2011). The CR technology is used for identification, utilization and management of vacant spectrum, known as Spectrum Holes or White Space (Rehan and Yasir, 2010). A spectrum hole is a region of space-time frequency, where a primary user is absent and a particular secondary use is possible. The concept of spectrum hole (white space) and spectrum in use are illustrated in Figure 1.1

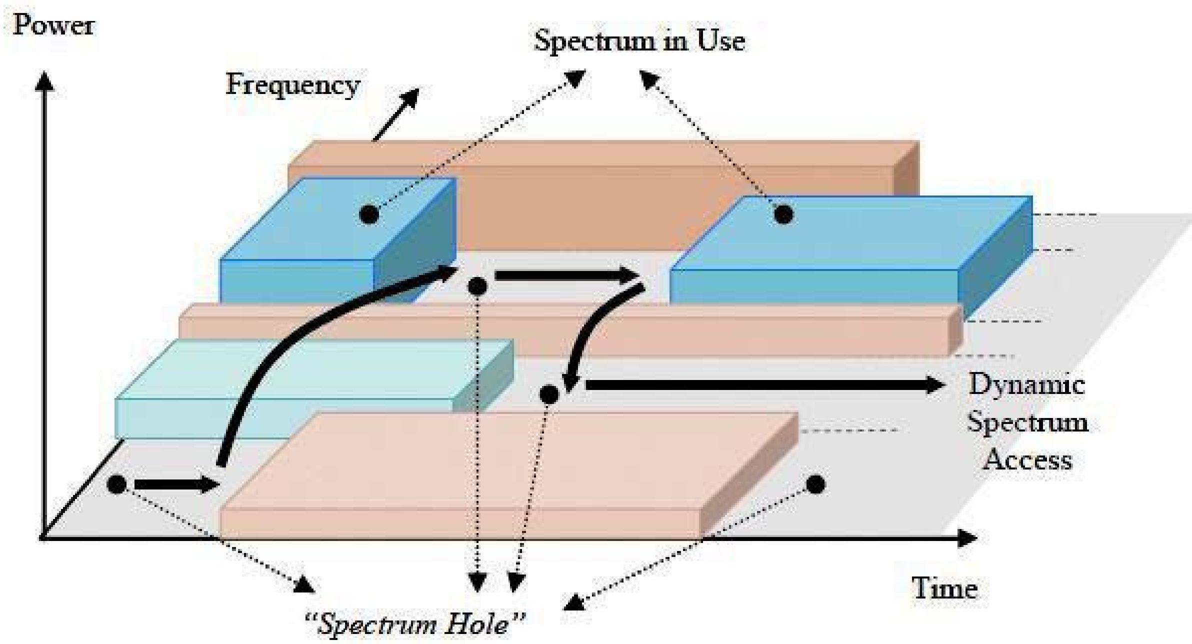


Figure 1.1: Illustration of Spectrum White Space Concept

Source: Akyildiz and Brandon 2010

As a matter of fact, the initial phase of the cognitive cycle consists of the sensing process. Hence, it is evident that reliable spectrum sensing is the most critical function of the cognitive radio process. By sensing and adapting to the environment, a cognitive radio has the ability to fill in the spectrum holes and serve its users without causing harmful interference to the primary user. Ultimately, a spectrum sensing scheme should give a general picture of the medium over the entire radio spectrum. This allows the cognitive radio network to analyze all parameters (time, frequency and space) in order to ascertain spectrum usage. From the aforesaid, it is essential that there should be efficient spectrum detection techniques that ensure secondary user transmissions, while safeguarding primary users.

Basically, the secondary user identifies "gaps" in the spectrum, known as spectrum holes or white spaces and puts them to use. These white spaces originate from partial or no occupations by the incumbent users, i.e. primary users (PU) for example Digital TV broadcasters. The secondary communication can be executed once the white spaces are identified in the spatial-temporal domain

(Baldini et al.2012). The function of spectrum sensing therefore, is to be aware of the spatial-temporal electromagnetic environment by determining the frequencies occupied by the PU.

A number of methods have been proposed for identifying spectrum opportunities in a scanned frequency band. Typically, spectrum sensing is grouped within three main detection approaches, namely, transmitter based detection methods, cooperative detection methods and interference based methods. Transmitter detection methods consist of matched filter, cyclostationary and energy detection. These techniques are further classified as coherent, semi-coherent or non-coherent; that is, either having complete, partial or no prior knowledge of the transmitter respectively. Schemes that are cooperative include centralized, distributed and cluster based sensing methods. Whereas transmitter and cooperative detection methods "perceive" spectrum to avoid interference to primary transmitters; interference based detection guarantees minimal primary receiver interference.

Geolocation however, is the identification of the real-world geographic location of an object, such as a radar source, mobile phone or Internet-connected computer terminal. It may also refer to the practice of assessing the location, or to the actual assessed location. Geolocation is closely related to the use of positioning systems but may be distinguished from it by a greater emphasis on determining a meaningful location (e.g. a street address) rather than just a set of geographic coordinates. The Haversine formula was employed to determine the distribution and positioning of different White Space Agents (WSAs) in relation with the White Space Device (WSD), in order to help determine the distance between two WSA. This is because it is an important equation in navigation, giving great-circle distances between two points on a sphere from their longitudes and latitudes. This can help in locating the WSAs and also to help determine the initial co-ordinate of the new facility (x_i, y_i) defined by centre of gravity using the great distance techniques. Hence, this directed towards spectrum optimization in white spaces using spectrum sensing and geolocation techniques.

1.2 Statement of the Problem

Spectrum sensing is the ability to detect radio signals and estimate the relative location of primary users in order not to interfere with them. Typically, spectrum sensing errors occurs at a very alarming rate. These errors include misdetection (MD) and false alarm (FA). Misdetection means that the spectrum is occupied by primary users (PUs) but the spectrum sensing result says it is available for secondary users (SUs), which will result in transmission collision and influence both PUs' and SUs' current transmission. However, false alarm occurs in the opposite way, when SUs believe that the spectrum is being used by PUs but actually the spectrum is idle, which will waste transmission opportunities for SUs. Wrong determination of the exact location of primary users, provoking unwanted interference or white space misdetection has become a big challenge in our today's wireless world. These aforementioned problems are in the increase due to increase in the demand of wireless devices. Therefore, the problem this work intends to address is the cohabiting of primary and secondary users without interference and continuity in secondary user's transmission by switching them to available spectrums.

1.3 Aim and Objectives of the Study

The aim of this study is to develop spectrum optimization in white spaces using spectrum sensing and geolocation techniques.

The objectives of this dissertation are to develop a system that should be able to:

a) Optimize the White Space Device (WSD) ability to learn spectrum availability.

b) Overcome false detection, misdetection of spectrum holes and eliminate interference.
c) Provide a spectrum sensing model that can find the exact location of white spaces and primary users.

1.4 Significance of the Study

As is known, to eliminate interference, the frequency reuse approach is followed in Digital TV planning similar to cellular network, avoiding the use of the same channel in two neighboring allotments. There are large areas where a certain group of TV channels are deliberately not used. They are called white spaces in TV spectrum (TVWS). Considering the great economical value of TV spectrum, it was proposed to use TVWS for low-power wireless networking on non-interfering (secondary) basis with the licensed (primary) DTV service. At the same time, restrictions imposed on white space devices (WSDs) to protect primary users should not devaluate spectrum for secondary use. The lack of knowledge about the locations of primary receivers as well as unreliability of estimation of the aggregate interference impact caused by the large number of secondary devices accessing the spectrum are reported to be among the key challenges for the use of TVWS which significantly this dissertation is looking forward in overcoming such. Since the research work will be providing WSDs with a list of available channels, the geolocation database will contain recommended parameters for path loss calculations as well as minimum distances which could be ensured for a certain inhabited locality.

TV White spaces are vacant, unused or interleaved frequencies located between broadcast TV channels in the Very High Frequency / Ultra High Frequency (VHF/UHF) range, which can be found between 474 MHz and 866 MHz. The VHF range includes channels two to thirteen (2 – 13), located between 30 and 300 MHz on the electromagnetic spectrum, while the UHF range includes channels twenty-one to seventy (21 – 70), located at 474MHz and above. The merit of propagating at lower frequency is that lower frequencies propagate better over distance and through walls. The merit of propagating at lower frequency is that lower frequencies propagate better over distance and through walls. The logic behind this is to utilize the unused spectrum of the incumbent systems for secondary access so that white space devices with low power can utilize this spectrum without causing interference with the incumbent systems. The unused Broadcast TV channels vary sparingly from one location to another. The TV White space devices will have the flexibility to sense, operate and log on to unused TV White Space channels. This is possible with the use of a database that houses unused channels called geolocation database technology which is the most concern of this work. It is worthy to mention that TV white spaces are very large, dormant spectrum resource that operator could benefit from providing low cost communications. Creating new technologies that will work with this TVWS spectrum with the motive of bridging the gap between digital divide for generations to come is very essential in this contemporary society.

This dissertation can be of great significant because the TVWS will bridge the gap of Digital Divide in Africa and in Nigeria especially. TVWS is an invaluable technology system that could foster the development of Nigeria’s ICT connectivity. When TVWS connectivity is achieved in most Nigerian States, it could supplement end to end broadband internet access coverage of rural and some parts of urban areas in Nigeria. Internet penetration would improve causing reduction in bridging the gap of digital divide. Information professionals need to teach young people how make to make efficient use of TVWS devices and understand their potential. The TVWS occupy a spot in the TV band delivering broadband to challenging rural areas and also making patchy urban Wi-Fi network seamless. With deployment of this work, incumbent operator could incorporate TVWS spectrum to provide seamless connectivity to areas with limited connectivity. A TVWS network in the UHF band of TVWS (600MHz) operating at the same power levels as current Wi-Fi devices (40 or 100 mW) needs around 16 times fewer access point to deliver the same coverage as Wi-Fi in 2GHz.This technology is well suited to provide low cost communication to rural communities with poor telecommunications infrastructure (Microsoft 4Africa Initiatives, 2013) affirmed.

However, the recent technology of cognitive radios offers the promise of being a disruptive technology innovation that will enhance the future wireless world. Cognitive radios are fully programmable wireless devices that can sense their environment and dynamically adapt their transmission waveform, channel access method, spectrum use, and networking protocols as needed for good network and application performance. It is anticipated that cognitive radio technology will soon emerge from early stage laboratory trials and vertical applications to become a general-purpose programmable radio that will serve as a universal platform for wireless system development, much like microprocessors have served a similar role for computation. The usage of the radio spectrum is significantly inefficient, and therefore the cognitive radio especially when it is optimize with good model can be extremely useful to exploit the unused spectrum from time to time, as long as the vacancy appears in the spectrum.

This study is significant due to the potential low power TVWS provides. These benefits include rural broadband; due to the favourable radio propagation characteristics for radio frequencies below 1 GHz, TVWS provides a communications environment for affordable wireless broadband services to rural and under-privileged communities in developing countries, particularly those sparsely populated countries with large geographical size. Trials in some countries have demonstrated the potential of TVWS technology to bridge digital divide3 and provide affordable access to the Internet to serve billions of people that are yet to be connected. Also in hot-spot coverage; TVWS could be used to provide fixed or mobile communications in hot-spots. This is similar to Wi-Fi hot-spots for use in public areas and in M2M communications; TVWS could be used to provide low data rate connections between sensors and devices used for the purposes of control, telemetry or remote monitoring. This can help resolve connectivity challenges to enable the evolving Internet of Things (IoT) or M2M communications. As such communications would demand tens of billions of telecommunications connections by wireless means, the long-range, low-power and low-cost characteristics of TVWS devices may be very suitable for meeting the challenges and demand of IoT/M2M in this regard.

This dissertation is also significant because the increasing demand for wireless connectivity, as part of the evolution of Information and Communication Technologies (ICTs) in the "digital information era", is driving the research into alternative forms of spectrum utilization in recent years. Securing access to efficient and sustainable ICT infrastructure has become a major goal worldwide, especially considering the vital role that ICTs play across all areas of human life, such as education, health, science, financial markets, security and civil protection, media, entertainment and business development. With a steep increase in the demand for mobile connectivity, the pressure on the supply side of the resource (the radio spectrum) becomes inevitable. While levels of spectrum demand are likely to vary across different regions depending on factors such as population density, geographic characteristics, and scale of development of broadband fixed networks; the rise of advanced consumer mobile devices and data-demanding mobile applications has considerably increased the usage of bandwidth in mobile spectrum bands in both mobile networks (e.g. 3G & 4G) and non-license local area networks (e.g. WiFi access). Also, emerging economies are embracing more and more the benefits of wireless broadband communication therefore realizing more value from the radio spectrum as a national infrastructure resource. It also provides a more affordable and flexible alternative for internet access to citizens and contributes in a more expeditious way to reducing the digital divide.

This dissertation is also significant because of the potential benefits of rural and urban broadband deployment. It means that the highly favorable propagation characteristics of the TV broadcast spectrum (as compared to unlicensed 2.4 or 5 GHz bands) will allow for wireless broadband deployment with greater range of operation (including the ability to pass through buildings, weather, and foliage) at lower power levels. Thus, the TVWS could be used to provide better broadband service in less densely populated areas. Hundreds of urban centers across the nation are already deploying first generation wireless local area networks to provide broadband access to residents. Use of the TVWS for such municipal broadband networks could increase the quality of service and decrease the deployment costs for these networks. More so, it will enhance public safety communication; that is to say that public agencies can have access to spectrum in the TV band; this would improve the capacity and quality of their networks, as well as facilitate their expanded use for e-government and consumer services. In emergencies, the TVWS can also provide supplementary services to augment public safety communications. It can also help in education and enterprise video conferencing. The TVWS could be used to give local high schools and middle-schools the same multimedia capabilities available to major university campuses: mobile, high speed Internet access for every student and teacher with a laptop or portable wireless device. In personal consumer applications, TVWS could be used to provide new services and applications to consumers by taking advantage of the improved signal reliability, capacity, and range of the TV broadcast spectrum. Wireless local area networks using low power and battery operated devices could enable new communications technologies that bring safety, convenience, and comfort to consumers in their homes. The favorable propagation and bandwidth characteristics of the TV broadcast spectrum could enable enhanced video security applications for commercial, residential, and government purposes. Some examples of security applications using the white space devices include perimeter video surveillance, robust wireless secure area monitoring, and childcare monitoring in the home or in childcare facilities. The highly favorable propagation characteristics of the TV broadcast spectrum will allow for wireless broadband deployment with greater range at lower transmits power levels. This could, therefore, reduce the number of cell/sites needed to cover a geographical area as compared with the conventional High Speed Packet Downlink Access (HSPDA), Wide Code Division Multiple Access (WCDMA) and Worldwide Interoperability for Microwave Access (WiMAX) systems and subsequently reduce the energy consumption.

Sensing only cannot provide adequate protection to the broadcasting service and the primary users, taking into account current technologies. This dissertation shall extend into employing geolocation with access to database and multiagents, which shall help record valid information about the available frequencies, exchange information about the locations, switch unlicensed users synchronously to the available frequencies and perform proper handover incase the transmitting device is moving to another location.

1.5 Scope of the Study

This research work is centered on the utilization of terrestrial communication technology as an alternative means of reducing the high competition in our spectrum world today. With the digital switchover, the so called digital dividend or white spaces appeared in the TV bands. TV White Spaces (TVWS) are vacant, unused or interleaved frequencies located between broadcast TV channels in the Very High Frequency / Ultra High Frequency (VHF/UHF) range, which can be found between 177MHz and 226 MHz on VHF and 474 MHz and 866 MHz on UHF. These white spaces are unused frequency bands within the TV transmission spectrum. There are also a range of other innovative usages of TVWS that might appear due to the favourable propagation characteristics. This study concern therefore, is optimal utilization of the white spaces within four locations namely Awka regions and environs, Nkpor and environs, Asaba and environs, Ubulu-Uku and environs. Though, there are other regions in Nigeria where the utilization of white spaces can also be harnessed. The study will be using spectrum sensing and geolocation techniques to determine the white space availability.

1.6 Limitations of the Study

The limitations encountered in carrying out this research work includes restrictions in the use of required instruments/tools by relevant companies, provision of separate secure network system for white spaces that will not interrupt with normal communication for that period. Another major constraint in this work is the different bodies involved and their respective policies.

1.7 Definition of Terms

Allele: This is the value a gene takes for a particular chromosome

Chromosome: This is the literal string encoded form of solutions that the classical genetic algorithm paradigm deals with.

Cognitive Radio (CR): This is a form of wireless communication in which a transceiver can intelligently detect the communication channels that are in use and the channels that are not and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. Put differently it is a radio that employs model-based reasoning to achieve a specified level of competence in radio related domains.

Crossover Operator: This is a recombination operator in genetic algorithm, where new solution in new generation is created by taking into account more than one solution from previous generation.

Fitness Function: A fitness function simply defined is a function which takes the solution as input and produces the suitability of the solution as the output.

Gene: This is one element position of a chromosome

Genetic algorithms (GAs): This a search-based optimization technique based on the principles of genetics and natural selection. It can also be seen as a computer programs that mimic the processes of biological evolution in order to solve problems and to model evolutionary systems.

Genetic Operators: These alter the genetic composition of the offspring. These include crossover, mutation, selection, etc.

Genotype: This is the population in the computation space. In the computation space, the solutions are represented in a way which can be easily understood and manipulated using computing system.

Geolocation: This is the identification of the real-world geographic location of an object, such as a radar source, mobile phone or Internet-connected computer terminal. It can be seen as the practice of assessing the location.

Mutation Operator: This is a recombination operator in genetic algorithm, where new solution is created from the single solution by changing some characteristics within it.

Mutation: This can be defined as a small random tweak in the chromosome, to get a new solution. It is used to maintain and introduce diversity in the genetic population and is usually applied with a low probability.

Optimization: This is the act of designing and developing systems to take maximum advantages of the resources available.

Phenotype: This is the population in the actual real world solution space in which solutions are represented in a way they are represented in real world situations.

Pixels: All the terrain covered by a geo-location database is represented as "pixels" which are squares of prearranged dimensions

Population: This is a subset of all the possible (encoded) solutions to the given problem. It can also be defined as a set of chromosomes.

Primary Users (PUs): These are known as licensed users that can access the wireless network resources according to their license.

Secondary Users (SUs): These are seen as unlicensed users that are equipped with cognitive radio capabilities to opportunistically access the spectrum.

Sensor: This is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat motion, moisture, pressure, etc.. The output is generally a signal that is converted to human readable display at the sensor location or transmitted electronically over a network for reading or further processing.

Spectrum Hole: This is defined as a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized.

Spectrum Sensing: A CR user can only allocate an unused portion of the spectrum. Therefore, the CR user should monitor the available spectrum bands, capture their information, and then detect the spectrum holes.

Spread Spectrum: This is a form of wireless communications in which the frequency of the transmitted signal is deliberately varied. This result in a much greater bandwidth than the signal would have if its frequency were not varied.

Transceiver: A transceiver is a combination transmitter/receiver in a single package. The term applies to wireless communications' devices such as cellular telephones, cordless telephone sets, handheld two-way radios, and mobile two-way radios. Occasionally the term is used in reference to transmitter/receiver devices in cable or optical fiber systems.

TV White Spaces: These refers to the unoccupied portions of spectrum in the UHF/VHF terrestrial television frequency bands

White Space Device (WSD): A device that can make use of the white space spectrum is often termed as white space device (WSD). It is an unlicensed device that operates in a spectrum that generally provides communications of broadband data and other services for consumers and businesses.

White Space Spectrum: This refers to unused broadcasting spectrum at individual locations which could be made available for other applications, such as wireless broadband Internet access. The spaces are commonly referred to as television “white spaces” (TVWS) in the terrestrial television frequency bands.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Electromagnetic Spectrum

Electromagnetic radiation is the propagation of energy that travels through space in the form of waves (Cave, 2002). It includes the visible spectrum (light), as well as infrared, ultraviolet and X-rays. The radio frequency spectrum is the portion of electromagnetic spectrum that carries radio waves. The boundaries of radio spectrum are defined by the frequencies of the transmitted signals, and are usually considered to range from 9 kiloHertz (thousand cycles per second) up to 3000 GHz (billion cycles per second) (Foster *et al.*, 2006).

Frequency (lower bound)	**Band**	**Example of Usage**
9 kHz	Very Low Frequency	Long distance radio
30 kHz	Low Frequency	Naval broadcast
300 kHz	Medium Frequency	Aeronautical communications
3000 kHz	High Frequency	Sound broadcasting
30 MHz	Very High Frequency	Private business radio
300 MHz	Ultra High Frequency	TV broadcasting
3000 MHz	Super High Frequency	Radar
30 GHz	Extremely High Frequency	Broadband wireless access
300 GHz	Not designated	

The key characteristics of spectrum are the propagation features and the amount of information which signals can carry. In general, the higher the frequency, the lower the propagation distance, but the higher the data-carrying capacity of the signal. These physical characteristics of the spectrum limit the range of applications for which any particular band is suitable, although some spectrum (such as in the UHF band, 300-3000MHz) is suitable for a wide variety of services and is thus in great demand. The growth in telecommunication services and radio technologies has led to an ever increasing demand for the use of spectrum among competing businesses both public sector and other users. Some relatively well established uses, such as analogue sound broadcasting, have continued to expand rapidly. Other established uses, such as defense and aeronautical radar, continue to utilize significant swathes (space) of spectrum. In addition, the growing appetite of society for mobile communications has led to a massive increase in demand for mobile radio-based applications. There are now millions of mobile telephones in the Nigeria. This growth, against the background of maintained demand elsewhere, is placing increasing pressure on the regulatory system to manage rapidly rising and shifting demand for spectrum.

Wellenius and Neto (2008), established that the radio spectrum is the range of frequencies used for wireless applications such as broadcast television and radio, cell phones, satellite radio and TV, wireless computer networks, Bluetooth, GPS, Police dispatch, and countless other general and specialized applications. It is difficult for these applications to utilize the same frequencies at the same time. For example, if a local broadcast TV station is using the same frequency as your cell phone, the cell phone wouldn't work very well due to interference from the TV station, or the TV picture would be fuzzy due to interference from the cell phone, or perhaps both.

In other to avoid such conflicts, the radio spectrum is carved out into different portions, and each portion is allocated to one or more service providers so that generally speaking, they may be able to co-exist with each other. In that sense, the allocation of the radio spectrum is similar to land use zoning: a particular area of a town or city may be zoned for industrial applications, and another area may be zoned for agricultural use, and yet another area may be zoned for residential use. Normally, homes are not built within industrial areas because industrial areas tend to be noisy and potentially more dangerous that most families or resident desire. The two applications – housing and industry – are generally incompatible so they are geographically separated by zoning. The same concept applies in spectrum allocations where the “zoning” is by frequency rather than geography. Of course, the spectrum is not devoid of potential conflicts despite the best planning. And even though a particular spectrum band is allocated to service providers that may be able to co-exist, coordination of frequency use among the allocated services (and even among users within the same service) is still usually required to mitigate interference.

The radio spectrum is used for a wide range of economic, social, cultural, scientific and developmental purposes with numerous number of end-user services such as communications used by firms, households and public bodies; critical safety and security communications used by defense forces, emergency services and air traffic control; various kinds of radar, broadcasting and scientific research. From an economic point of view, the radio spectrum is a resource used by a wide range of entities including public bodies such as defense or emergency services for a number of applications which include narrow and broadband mobile telecommunications, broadcasting, aeronautical, and marine communications, and for scientific applications such as radio astronomy and environmental sensing. The use of the radio spectrum is at an all-time high due to the explosion in the demand for mobile voice, data, and entertainment. Consequently, the demand for additions, modifications and waivers to existing spectrum allocations is also growing.

2.2 Review of Existing Works

The usable electromagnetic radio spectrum is a very valuable natural resource and has a limited span. In development of spectrum sensing techniques and other basic tasks, the main goals of a cognitive radio network are the following: (i) Provide highly reliable communication to all users of the network, wherever and whenever required (ii) Provide a way for efficient utilization of the radio spectrum with cost effectiveness (Sharan & Wankhed, 2010). In other words, the main target is to maximize the probability of detection keeping the probability of false alarm as low as possible while minimizing the design and computational complexity, and time to sense or detect the radio.

The growth of wireless communication relies on the availability of radio frequency for new services. More efficient spectrum allocations are required to serve the increasing data per user. The major regulatory bodies are formulating new spectrum management techniques to forge the growing spectrum scarcity. Exclusive use of spectrum is proved to be inefficient in many spectrum occupancy measurement campaigns. TV broadcasting is not using the allocated frequency in some geographic areas, creating coverage holes known as TV white spaces. Both the industry and the regulators are investigating the capability of TVWS, as a potential source of spectrum for emerging wireless services. Many authors has explored the possibility of the using the TVWS in different regions via different sensing techniques. Some works in this area were reviewed in this work.

Gbenga-Ilori and Sanusi (2014), proposed maximizing TV white space in Nigeria using an optimized SFN and k-SFN network design. In their work the current spectrum occupancy of UHF and VHF band by analogue terrestrial television was determined. The spectrum was re-planned for future DTV services by considering the size of the network, the location of the transmitters in each of the geo-political zones of the country, the type of coverage and variation in regional programming. Results from the network plan showed that 8 multiplexes, using 20 UHF channels can be used to broadcast 129 programmes to achieve a spectrum savings of 168MHz which amount to 51.22% of the present analogue television spectrum use. Their work did not take into consideration the introduction of new transmitters which can make a channel that is available at one time for TVWS become unusable due to SFN. Also their work did not specify how these channels can be allocated to white space devices. The work of Sindiso *et al.*, (2014) optimization of a TV white Space broadband market model for rural entrepreneurs, presented a competitive scenario within the context of spectrum management wherein licensed users of spectrum called primary users compete to offer services to an unlicensed users called secondary users. They claimed that from a primary user perspective, the cost of providing a service to a secondary service is modeled as a function of QoS degradation. This being a game, Nash equilibrium is considered to be the optimal solution. Throughout their work there was no provision for sensing model for the scanning of TVWS availability. Takyi *et al.,* (2016) in their work collaborative neighbour monitoring in TV white space networks employed collaborative sensing method to allow each secondary user to monitor it neighbor to ensure there is no spectrum abuse by any secondary users so as to improve spectrum fairness in dynamic spectrum access (DSA) networks because of the prevailing problem of false detection. Zlobinsky and Johnson (2016) did a channel selection algorithm for a TVWS mesh network. The main objective of their work was to develop a channel allocation (CA) algorithm to be used in conjunction with a routing algorithm to optimize the throughput of a TVWS mesh network in the presence of primary users and other possible dynamic secondary user interferers. They discovered some constraint in achieving their goals, one of them is the mandatory use of the Geolocation spectrum database and method of access to the database. Saeed *et al.,* (2015) proposed DynaWhite architecture, that will be responsible for orchestrating the detection and dissemination of highly dynamic, real-time, and fine-grained TV white space information, based on both TV transmitter and receiver information. This proposed architecture can significantly alter the perception of white spaces, especially within urban cities due to the problem of connecting to the database.

Vinayak *et al.,* (2017), proposed spectrum sensing optimization by sensing threshold and duration for cognitive radio networks, in their work joint optimization of the sensing threshold and the number of sensing samples in the energy detector was proposed, though they claimed that the joint optimization can significantly increase in the average aggregate opportunistic throughput and decrease the mean time to detect spectrum hole of both primary and secondary users but interference between them were never considered. Asif *et al,* (2017), proposed a coexistence decision-making (CDM) system for efficient TV whitespace (TVWS) sharing among whitespace objects (WSOs). In their work they claimed that the proposed system was considered versatile in functionality as it jointly takes care of three distinct channel allocation features: (a) optimizing system quality of service (QoS) performance metrics, (b) improving TVWS utility, and (c) satisfying WSO channel demands, though they never made analysis of the existence of the TVWS. Mahesh (2018), proposed a planning tool for TV White Space deployments, in his work he came up with a planning tool which determines the best locations for placement of secondary antennas based on secondary base station's coverage area, population of the region, throughput required and other such parameters. He employed Shannon's theorem, to determine the optimal placement of secondary TV white space antennas.

Manjurul and Barman (2018) did work on TV White Space in rural broadband connectivity in case of Bangladesh toward "Vision 2021". In their work, a starting point towards the development of fully operational white space networks for rural broadband connectivity and better utilization of white spaces in Bangladesh was considered. They suggested that a study on combining both spectrum sensing and geolocation databases for TVWS access will be the major agenda of our future work. Quantization of TV White space regions for a broadcast based geolocation database was proposed by (Garima, and Animesh, 2017). In their work the key issue addressed was quantization or digital representation of the protection regions. A fast algorithm for optimal quantizer design was developed. They claimed that algorithm minimizes the white space area identified as protection region, while ensuring that protection region is not labeled as white space region due to quantization.

The most important aspect of cognitive radio technology is spectrum sensing which is defined according to Ghasemi and Sousa (2008), as the task of locating spectrum holes by sensing the radio spectrum in the local neighborhood of the cognitive radio receiver in an automatic manner. Also another goal of cognitive radio is the Opportunistic Spectrum Access (OSA) which facilitates exploitation of local spectrum availability without deleterious effect to the primary user. The foundation on which the cognitive radio paradigm is built is the OSA. With this paradigm, devices would be capable of sensing the environment over swaths of spectrum to find spectral holes and expeditiously make use of frequency bands that are not occupied by primary users, inducing no harm to the legacy system in the process. Basically, the secondary user identifies "gaps" in the spectrum, known as a spectrum holes or white spaces and puts them to use. Oyibo (2014), indicated that white spaces originate from partial or no occupations by the incumbent users, i.e. Primary Users (PU) like Digital TV broadcasters. However, a number of sensing techniques/methods have been proposed in identifying spectrum opportunity. These different methods are analyzed with their short comings identified.

The Energy Detector Based Approach (EDBA), also known as radiometry or periodogram, is the most common way of spectrum sensing because of its low computational and implementation complexities. Pawelczak (2011) study shows that the principle of energy detector is finding the energy of the received signal and this compared with the threshold. It involves the ability to ascertain the availability of an active communication link when the transmitted signal structure is unknown. Energy detection (also known as non-coherent detection) is the signal detection mechanism using an energy detector to specify the presence or absence of signal in the band. The most often used approaches in the energy detection are based on the Neyman-Pearson (NP) lemma. The NP lemma criterion increases the probability of detection (P_d) for a given probability of false alarm (P_{fa}). It is an essential and a common approach to spectrum sensing since it has moderate computational complexities, and can be implemented in both time domain and frequency domain. To adjust the threshold of detection, energy detector requires knowledge of the power of noise in the band to be sensed. Energy detection is not optimal but simple to implement, so it is widely adopted. The signal is detected by comparing the output of energy detector with threshold which depends on the noise floor. Compared with energy detection, matched filter detection and cyclostationary detection require a priori information of the PUs to operate efficiently, which is hard to realize practically since PUs differ in different situation.

Originally, EDBA approach was outlined in the classic work by Urkowitz (1967), were it was assumed that the signals can be determined in nature, existing over at band limited Gaussian noise channel and exact noise variance can be known. In this proposal, by applying the sampling theorem to estimate the received signal energy and from the chi-square statistics of the resulting sum of the squared Gaussian random variables, signal detection was reduced to a simple identification problem, formalized as a hypothesis test. Based on this assumption, he proposed a model for detection of energy in deterministic signals under AWGN in the time domain consisting of passing the received signal *y(t)* through

$$H(f) = \begin{cases} \frac{2}{\sqrt{N_0}}, \\ 0, \end{cases}$$

an ideal Band Pass Filter (BPF) with a center frequency f_o and bandwidth W, with transfer function;

$$| f - f_0 | \leq W$$

$$| f - f_0 | = W$$

Where N is the one-sided noise power spectral density which normalizes if found convenient to compute the false-alarm and detection probabilities using the related transfer function. From these, the signal is then squared and integrated over an interval T, to produce a test statistic, V, compared to a threshold, k. The receiver makes a decision on the target signal, based on the condition that the threshold is exceeded.

Since then however, energy detection analysis has been considered with several modifications in literature. Other researchers that proposed the energy detection method include Energy detection was also presented by Sahai *et al.,* (2006), according to their proposal if the previous information of the PU signal is anonymous, then this energy detection method is optimal for detecting any zero-mean constellation signals. In their approach, in order to determine whether the channel is occupied or not, the received signal strength indicator (RSSI) or radio frequency (RF) energy in the channel is measured. Also, in order to select the bandwidth of interest; the input signal is filtered by a band pass filter. After getting the square of the output signal, it is integrated over the observation interval. At the end, the output from the integrator is compared to a predetermined threshold value to conclude the presence or not of the PU signal.

The proposal made by Ganesan and Li (2005), Shankar and Challapali (2005), Digham *et al.,* (2007), Yuan *et al.,* (2007), was based on the fact that when the receiver cannot gather sufficient information about the primary user (PU) signal, for instance, if the power of the random Gaussian noise is only known at the receiver, the optimal detector is the energy detector. In order to measure the energy of the received signal *s(t)*, the output of bandpass filter with bandwidth *W* is squared and integrated over the observation interval *T*. Finally, the output of the integrator, *Y*, is compared with a threshold λ to decide whether a licensed user is present or not. However, the performance of energy detector is susceptible to uncertainty in noise power. To solve this problem, a pilot tone from the primary transmitter can be used to help improve the accuracy of the energy detector. Another shortcoming is that the energy detector cannot differentiate signal types but can only determine the presence of the signal. Thus, the energy detector is prone to false detection triggered by unintended signals.

In the work done by Kostylev (2002), Maharjan *et al.*, (2007), Yunfei (2010), Abdulsattar and Hussein (2012), Hossain *et al.*, (2012), Olabiyi and Annamalai (2012), however, detecting unknown deterministic signals was developed as a binary hypothesis test problem. With this, the detection statistics was based on the Neyman-Pearson criterion, wherein the performance of the system was expressed in terms of false alarm and detection probability. These articles for the most part, deal with the sophistication, while leaving out the reliability and accuracy of this technique. With the aim of improving the overall sensing performance while scanning wide frequency bands, Farhang (2008), proposed another form of this method using rows of filters (filter banks). With this, a collection of N sub-filters was used to divide whole frequency bands of interest into N sub-bands. The i^{th} sub-filter of the bank was used to extract spectral information from the i^{th} sub-band of interest with a normalized center frequency. It is noteworthy that filters of this nature are not very reliable in implementation since the frequency response of the filter influences the quality of estimated power in the sub-band.

Shehata and Tanany (2009), proposed an adaptive scheme to explore energy detection based spectrum sensing. This method comprises a side detector applied to monitor the spectrum to improve the detection probability. The system model consists of a primary user (PU) transmitting a Quadrature Phase Shift Keying (QPSK) modulated signal within a 200KHz bandwidth. The sampling frequency is set 8 times the bandwidth and a 1024-point Fast Fourier transforms (FFT) is used to compute the received signal energy. Results presented indicate improved execution of spectrum sensing during reemergence of the PU in the wake of the sensing time. Nonetheless, from the choice of bandwidth under consideration, this study is restricted to only frequency modulated (FM) signals.

Akyildiz *et al.,* (2006), Ziafat *et al.,* (2011) Pawełczak (2011), (Garhwal *et al.,* 2012), also proposed energy detection based approach for spectrum sensing. Their method was based on Neyman-Pearson (NP) lemma. According to the method the NP lemma criterion increases the probability of detection (P_d) for a given probability of false alarm (P_{fa}). The method does not guarantee optimality though it is simple to implement.

Numerical analysis of the energy detection method over fading channels was presented by (Reisi *et al.,* 2010). In their work, deviating from exact solutions since there are computationally complex, the authors derive approximate closed form expressions for the probability of detection (P_D) for Nakagami fading channels and also obtain a rule of thumb expression relating the number of samples (sensing time) to the signal-to-noise- ratios (SNRs) for a given P_D and P_{FA} regarding Nakagami fading models.

Energy detection using a multiple antenna system based approach was proposed by Noguet (2009), the method assumed to have M antennas at the receiver. The channel between the primary user transmitter and i -th antenna of the CR receiver was modelled as a Rayleigh flat-fading channel with gain hi , with the hi's being i.i.d. random variables with unit variance. When there is a primary signal transmission, the signal $s(t)$ is received at the i –th receiver antenna over channel hi and additive white Gaussian noise $n(t)$. The received signal at the i -th antenna can then be written as: $ri(t) = his(t) + n(t)$. The received signals $ri(t)$ are processed by a certain technique resulting in the output signal $y(t)$, which is input to the energy detection algorithm.

Shuisheng (2011), proposed a method to determine the sensing threshold and minimum distance for the secondary users called Energy Detective method. By which the secondary user controls its sensing threshold and transmission power to guarantee the minimum decodable SINR for the primary receiver. By numerical analysis of interference to both systems using this method shows that coexistence of both systems is possible if the secondary users locate outside the minimum distance decided. This method is found to be most suitable where primary user's parameters are unknown.

Ghasemi and Sousa (2005), proposal presented an idea which was to measure the received energy on the specific portion of the spectrum, i.e., channel, for a certain period of time. If the measured energy is below a threshold value, the channel is considered available. Its simplicity and low signal processing requirement make this method very attractive for cognitive radio sensor network (CRSN). However, it has a number of drawbacks. Energy detection requires longer measurement duration to achieve a certain performance level compared to matched filter method. Furthermore, the performance of this method highly depends on variations of the noise power level. Therefore, in case of a small increase in detected energy, it is impossible to understand whether the reason is a primary user activity or an increase noise power level.

Shukla and Sharma (2013), analyzed the energy detection technique using Power Spectral Density (PSD). Power signals are the limiting case by assuming that the power signal is restricted in the interval (-T, T). PSD is the measurement of the power content in the signal. It is the frequency domain plot between powers per Hertz versus frequency. For calculation of energy content in a signal we had to sample the signal and then measure the PSD. Their proposal took a sinusoidal signal is taken as an input. This input sine wave is then modulated by 5 different carrier signals depicting 5 different channels. Also as the carrier signal ranges from (-∞, ∞) it will be a power signal. To measure the energy content we combine the output from each modulator and sample the combined signal by a sampling frequency of 10 KHz. The sampled signal is then used to obtain the PSD of the spectrum. In their result they claimed that the channels that are absent have low power level near their respective carrier frequency in the obtained PSD of the spectrum. That means no modulation process is going on or the input was absent. The input was referred to as primary user. That means that when a channel is showing low power level in the PSD the primary user is absent and the channel can be allotted to other secondary user.

Li *et al.,*(2011), proposed double threshold detection with channel selector for energy detection. In their method, the cognitive user receives signals by selecting the maximum SNR channel, so it can effectively detect the PU signal in Rayleigh fading environment.

In the work of Atapattu *et al.,*(2011), detection performance of an energy detector used for spectrum sensing in CR networks was investigated over channels with both multipath fading and shadowing. Their analysis focuses on two fusion strategies: data fusion and decision fusion. Under data fusion, upper bounds for average detection probabilities are derived for four scenarios: i) single cognitive relay; ii) multiple cognitive relays; iii) multiple cognitive relays with direct link; and iv) multi-hop cognitive relays. Under decision fusion, the exact detection and false alarm probabilities were derived under the generalized "k-out of-n" fusion rule at the fusion center with consideration of errors in the reporting channel due to fading. In their work results were extended to a multi-hop network as well. Their analysis focuses on the derivation of a closed form expression for the average missed-detection probability over Rayleigh fading and Nakagami-m multipath fading and lognormal shadowing as well

In the work of Kim *et al.,* (2010), an experimental study of energy detector based spectrum sensing is realized using software defined radio test-bed. Since the choice of the theoretical threshold relies largely on acquisition of a perfect knowledge of noise power (which is challenging in a real environment), the authors applied a histogram based method to determine an appropriate threshold. The offered method eliminates the need to model the test statistics in energy detection by collecting a sufficiently large number of samples to obtain two histograms of the test statistics under hypothesis H_0 and H_1. Based on these histograms, a threshold, Ph_{th}, is chosen to meet a design criteria of the false-alarm and misdetection probabilities. The construction of the histogram method however, requires large number of samples to ascertain a wide range of noise power in the signal; making selection of these thresholds requires a considerable amount of time. Added to this, the proposed model functions more like an on-line process; which should be done before energy detection.

Chang (2012), proposed a detection framework for the application of spectrum sensing optimization to provide clear guidance on the constraints on sensing and detection model. This framework ensured that the signal model accurately reflects practical behaviour while the detection model implemented was also suitable for desired detection assumption. His proposal is based on non-stationary primary user, energy detector, waveform based detector and cyclostationary based detector were formulated with respect to the duty cycle exhibited by the primary user.

In the work done by Qing and Jia (2010), detection of signals operating in a band of frequencies was executed by splitting spectrum into multiple channels using a theory of quickest detection. Quickest detection refers to real-time detection of changes as quickly; after they occur. Here, the authors studied a case where single narrowband energy detector node is to sense multiple channels. This detector operates with a predetermined belief factor - based on past primary user action to ascertain which channel to sense in the future. This approach proved to reduce sensing time; ensuring a certain false alarm rate is met. Liang and Blostein (2011), extended this to a case involving multiple narrowband detectors employed to sense wide band channels, with an assumption that the number of channels are more than the number of detectors. Similar analysis assumes a belief factor, adopted to show more spectrum holes can be harvested, as opposed to concentrating each detector on a particular narrowband at all times. An underlying premise from these studies so far was the dynamic range of detector spanning entire bandwidths, while sensing a narrowband per time. Moreover, these assumptions will involve fast changes in the frequency of the local oscillator which imposes its own limitation to the viability of this approach. More so, the analysis so far relies heavily on accurate knowledge of the distribution of primary user activities to reach an optimum detection.

In the work of Mohamad and Sani (2013), Binary Phase Shift Keying (BPSK) signal were proposed. The modulation signal was generated randomly as the input signal to the energy detector to analyze the spectrum frequency. The authors obtained probability of detection throughout the detection process using various numbers of samples and SNR value.

Gomathi *et al.*, (2014), assumed that the input signal *y(t)* is real, this signal was transformed into digital form using an analogue-to-digital converter (ADC). After that, the received signal is squared and averaged, and then the output was compared with a threshold, λ, to decide if the primary user existed or not. In the proposal made by Yu *et al.,* (2012), the relationship of energy detection performance and detection sensitivity with average noise power fluctuation in short time was investigated. Detection performance and detection sensitivity drops quickly with the increment of average noise power fluctuation and becomes worse in low signal-to-noise ratio. A new energy detection algorithm based on dynamic threshold was presented. They claimed that theoretic results and simulations show that the proposed scheme removes the falling proportion of performance and detection sensitivity caused by the average noise power fluctuation with a choice threshold, and also improves the antagonism of the average noise power fluctuation in short time and obtains a good performance.

These above proposals for energy detector technique considered in this literature have the advantages of low complexity, ease of implementation and faster decision making probability. In addition, energy detection is the optimum detection if the primary user signal is not known. The method cannot be effective due to the following drawbacks – The threshold used in energy selection depends on the noise variance, Inability to differentiate the interference from other secondary users sharing the same channel and with the primary user, it has poor performance under low signal-noise-ratio (SNR) conditions, this is because the noise variance is not accurately known at the low SNR, and the noise uncertainty may render the energy detection useless, it does not work for the spread spectrum techniques like direct sequence and frequency hopping.

Another sensing method is the matched filter. Unlike energy detection, a matched filter is a linear filter designed to maximize the output signal to noise ratio for a given input signal Proakis (1995). In matched filter detection, the secondary user prior knowledge of primary user signal is needed. This information according to Subhedar and Birajdar (2011), includes modulation format, carrier frequency, order, pulse shape, and packet format, they are to be known to the secondary user before-hand. These features are used to detect and implement a matched filter when primary users have pilots, preambles, synchronization words or spreading codes, leading to coherent detection. This method according to Shipra and Ghanshyam (2011), is known as the optimum method for detection of primary users when the transmitted signal is known. Many researchers have proposed different methods on the matched filter based technique.

Davenport *et al.,* (2006), Haupt and Nowak (2007), proposed compressive detector using matched filters. In their work they claimed that despite the drawbacks of matched filter it can be applicable to certain class of primary network with uniform signal characteristics and when information about the signal is known in prior.

Khaled and Wei (2009), applied matched filter spectrum sensing approach to sense the presence of a digital television (DTV) signal. First, the pilot tone is detected by passing the DTV signal through a delay-and-multiply circuit. A decision is reached if the squared magnitude of the output signal is larger than a threshold; by which case presence of a DTV signal is established. But in the generalized SS scenario however, use of a matched filter can be severely limited since complete information of the transmitted primary user (PU) signal is hardly available. In the work of Gholamipour *et al.*,(2011), a reconfigurable matched-filter based spectrum is proposed to tackle the flaws associated with the traditional matched filter design. The generic filter method is the option adopted. In this set up, the coefficient set of the generic filter is changed periodically to scan spectrum of the wireless channel associated with each standard. The effectiveness of this technique relies on reconfiguring the filter to implement the numerous communication standards available. In contrast, weighing the variability of the filtering requirements for different standards, the generic filter will have to be designed for the worst case to accommodate all standards. Apart from this, the features of generic designs are slow and large with some degree of power consumption, making a generic implementation of the filtering block less attractive. The second option implemented is a design of optimized individual filters for each wireless standard; termed “space-multiplexing”. Nonetheless, this would increase the size of the circuitry, not scalable with a number of standards; while power consumed is not featured in the signal analysis.

In the work of Shobana *et al.,* (2013), a match filter was proposed to sense unused spectrum for Orthogonal Frequency Division Multiplexing, wireless local area network (OFDM WLAN) (IEEE802.11a) by exploring the signals presence in minimum time. This is executed by incorporating an optimal threshold selection that increases sensing accuracy and interference reduction produced by the secondary network.

Ghauri *et al.*, (2013), affirmed that matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal.

Vadivelu *et al.*,(2014), proposed a matched filter based spectrum sensing for cognitive radio at low signal to noise ratio. In their proposal they claimed that with the existing knowledge of the regulated system parameters, the fusion Centre can make a global sensing decision consistently without any additional requirements such as channel state information, prior information and prior prospects about the primary user's signal. In their work numerical results in terms of receiver operating characteristics show that the sensing performance of the proposed matched filter based system out performs the performance of the adaptive Takagi and Sugeno's fuzzy energy based system model at low Signal to Noise Ratio.

Although, match filters are optimal and the coherency requires less time to achieve high processing gain, it is less attractive for practical purposes as it requires prior knowledge of the primary signal. Though information regarding a signal can be stored in memory, the synchronization and channel equalization remains inevitable. Besides, a secondary user or spectrum detector requires extra circuitry to achieve carrier synchronization. So, in wideband spectrum sensing even though we have prior information regarding the signal, the dynamic signal characteristics in wideband communication makes it less feasible. Also a cognitive radio would need a dedicated receiver for every primary user class.

Moreover, since cognitive radio needs receivers for all signal types, the implementation complexity of sensing unit is impractically large. It also has large power consumption as various receiver algorithms need to be executed for detection.

Cyclostationary feature detection is another method for spectrum sensing. This method exploits the periodicity in the received primary signal to identify the presence of Primary Users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference (Gardner, 1991). Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing.

Many authors proposed this method for spectrum sensing. Aparna and Jayasheela (2012) affirms that exploiting this periodicity in the received primary signal to identify the presence of primary users makes this method possess a high noise immunity compared to other spectrum sensing methods

Spectrum sensing based on cyclostationarity features has received considerable attention from the academic community from the initial work by Gardner (1991) which highlighted that most of the communication signals can be modeled as cyclostationary that exhibits underlying periodicities in their signal structures.

Oner and Jondral (2004), proposed Cyclostationarity based air interface recognition for software radio systems. In their work they showed that wireless transmissions in general show very strong cyclostationarity features depending on their modulation type, data rate and carrier frequency etc., especially when excess bandwidth is utilized. Therefore the identification of the unique set of features of a particular radio signal for a given wireless access system can be used to detect the system based on its cyclostationarity features. They claimed that Spectrum sensing based on cyclostationarity performs very well with very low signal-to-noise ratio.

Sutton *et al.,* (2008), proposed an alternative approach to feature detection using signatures embedded in a signal to solve a number of challenges associated with dynamic spectrum access applications; especially receiver complexity. Using a flexible cognitive radio platform, implementation of a full Orthogonal Frequency Division Multiplexing (OFDM) based transceiver using cyclostationary signatures is presented and the system performance is examined from experimental results. Although, methods presented therein are OFDM specific, similar techniques can be developed for any type of signal.

In the work of Cabric and Broderson (2005), Fehske *et al.,* (2005), Ghozzi *et al.,* (2006), Khambekar *et al.,*(2007), they showed that cyclostationarity feature detection was a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals.

In the work of Hou-Shin *et al.,* (2007), the authors study spectrum detection in a low SNR environment applying the noise rejection property of the cyclostationary spectrum. This is computed by measuring the cyclic spectrum of the received signal. Statistics concerning the spectrum of the stationary white Gaussian process were fully analyzed. An application to the IEEE 802.22 WRAN1, alongside analytic derivation of the probability of false alarm is also presented. Since the stationary Gaussian process has a zero-valued spectral correlation density function (SCD) at nonzero frequencies, the desired signal is detected by computing the SCD - provided the signal is cyclostationary - such that its cyclic spectrum is not identically zero at some nonzero cyclic frequency.

A detector for OFDM signals based on cyclostationary features is presented by Axell and Larsson (2011), their work exploits the inherent correlation of

Orthogonal Frequency Division Multiplexing (OFDM) signals obtained by data repetition in the cyclic prefix; i.e. using knowledge of the length of the cyclic prefix and length of the OFDM symbol. The authors demonstrated that detection performance improves by 5dB in applicable cases.

Choi *et al.*, (2007), proposed cyclostationarity based collaborative detection where binary decisions of the secondary users using cyclic detectors are combined. Optimal test thresholds at the fusion center (FC) and the secondary users are determined using an iterative algorithm. However, due to the iterative nature of the algorithm, multiple expensive transmissions between the FC and the secondary users are required.

Koivunen *et al.*, (2009), proposed a collaborative cyclostationary spectrum sensing for cognitive radio systems. In their work, cyclostationary spectrum sensing of primary users in a cognitive radio system was considered. They proposed single user multicycle detectors and extended them to accommodate user collaboration. They also proposed a censoring technique for reducing energy consumption and the number of transmissions of local test statistics during collaboration. They claimed that combining cyclostationary detection and user collaboration with censoring provides a powerful energy efficient approach for spectrum sensing in cognitive radio systems and that their approach is able to distinguish among primary users, secondary users, and interference.

Chakravarthy and Wu (2007), proposed cyclostationary spectrum sensing method which was used to detect spectral correlation peaks of a PU signal, in their work they first estimated the spectral correlation function (SCF), which was a two dimensional spectral map showing the spectral correlation peaks. Mishali and Eldar (2010), also proposed sub-Nyquist cyclostationary feature detection. In their work they used Modulated Wideband Converter (MWC) as a front-end.

Cohen *et al., (*2011), showed that one approach to perform sub-Nyquist cyclostationary feature detection is to first recover the Nyquist samples, then estimate the SCF, and perform feature detection.

Tian (2011), considered cyclostationary detection using sub-Nyquist samples, the spectral correlation function (SCF), reconstruction was performed blindly with no a priori knowledge of the carriers and bandwidths of the signals to be detected

Rebeiz *et al.*, (2011), proposed cyclostationarity-based low complexity wideband spectrum sensing using compressive sampling. In their work they exploit the sparsity of the two-dimensional spectral correlation function (SCF), and propose a reduced complexity reconstruction method of the sub-Nyquist SCF from the sub-Nyquist samples.

They analyzed the trade-off between compression ratio and sensing time, and showed that the SCF reconstruction, and concluded that signal detection, is feasible as long as the compression ratio is above the compression wall.

Cyclostationary spectrum sensing was also investigated in the work of Hosseini *et al.*, (2010), which addressed the problem in many applications, for a specific signal, the statistical characteristics were not the same in two adjacent periods, but they change smoothly. So, the periodicity which appears in the aforementioned processes, does not necessarily lead to a pure cyclostationary process, but leads to an almost cyclostationarity which causes limitation on using cyclostationary features. The authors suggested a new estimator for almost cyclostationary signals.

In the work of Thamizharasan *et al.*, (2013), cyclostationary spectrum sensing method for identifying the presence of primary user was introduced which uses the concept of periodicity in OFDM signals. They claimed that the proposed scheme was robust for the detection of primary user signal with guard interval insertion in the OFDM signals which use the concept of periodicity.

Cyclostationary based spectrum sensing in cognitive radio: windowing approach was proposed by Mishra *et al.*,(2014)**,** in their work they studied how to sense a particular spectrum by using cyclostationary detection method. The received signal was passed in the output side into different windows and they found out the autocorrelation of different signals from each window and verified the channels occupied by the primary users as well as the channels not occupied by the primary users. The channels that are not occupied by the primary users were assigned to the secondary users. Their work shows that very fewer variations occurred during the evaluation of no. of frequency components to detect presence of PU and absence of PU by taking multiple iterations. They claimed that the best performance can be achieved by passing the signal through the "Rectangular window" and "Kaiser window".

In the above reviewed cyclostationary based detection methods, though the signals which are used in several applications are generally coupled with sinusoid carriers, cyclic prefix, spreading codes, pulse trains etc. which result in periodicity of their statistics like mean and auto-correlation. Such periodicities can be easily highlighted when cyclic spectral density (CSD) for such signals is found out. Primary user signals which have these periodicities can be easily detected by taking their correlation which tends to enhance their similarity. Fourier transform of the correlated signal results in peaks at frequencies which are specific to a signal and searching for these peaks helps in determining the presence of the primary user. Noise is random in nature and as such there are no such periodicities in it and thus it doesn't get highlighted on taking the correlation. The method faced with the following challenges: High computational complexity since all the cycle frequencies are calculated. Knowledge of specific transmitted signal parameters is needed, long sensing time etc.

Another sensing method reviewed in this dissertation is the interference based detection as proposed by MacDonald and Ucci (2007), Perera and Herath (2011). This theoretical method employs an interference temperature model; which is a measure of how well a radio operating within a particular modulation scheme and protocol can tolerate interference in its spectrum space. This follows the fact that signal power received at a primary receiver reduces exponentially with distance; continuously till it reaches a level of the noise floor. Though a primary transmitter still operates at this point, the receiver handles this process as noise and not transmission. This makes it possible for a secondary user to utilize the channel, since no interference is introduced to the primary users' communication (as the primary receiver is not in receiving mode). This method however, is far more challenging; since the prime problem faced with an implementation of this technique will be in determining specific receiver interference temperature levels for the various communication standards. The method according analysis made by Umar and Sheikh (2012), was declared to be non-implementable and not appropriate approach to spectrum sensing.

Cooperative sensing detection is another sensing method considered in this review. In this method group of CR's share sensing information so as to get a more efficient result. In this process group of secondary user (SU) collect the information regarding channel occupancy and maintain this information into spectrum map represented by bit-vector. SU periodically transmit it to the Central Coordinator as part of control message. Central coordinator takes bitwise-OR of spectrum maps, to determine the set of ultra high frequency (UHF) channels available at all of the nodes. After that, the central coordinator selects the best available channel and broadcast it back to SU. This method was proposed by Cabric *et al*., (2006), Akyildiz *et al.*,(2010), their proposal showed that through this technique of cooperation amongst users, robustness is achieved without severe demands on individual radios; thus enhancing effective primary detection as analyzed by Mishra *et al.,*(2006). In addition, cooperation can solve hidden primary user problem and it can decrease sensing time. However, challenge of cooperative sensing among others includes developing efficient information sharing algorithms and increased complexity.

The review also considered the three approaches for cooperative spectrum sensing as proposed by Li *et al.,* (2009) and the authors mentioned above. These methods are centralized sensing, distributed sensing and Relay-assisted cooperative.

In centralized sensing, a central unit collects sensing information from cognitive devices, identifies the available spectrum, and broadcasts this information to other cognitive radios or directly controls the cognitive radio traffic. Here there is a central node called fusion center (FC) or central processor controls within the network. This approach was analyzed by Ghasemi and Sousa (2007). The goal in this approach is to mitigate the fading effects of the channel and increase detection performance. The drawback of this method can be seen with the case of a large number of users, the bandwidth required for reporting becomes huge. Another weakness of the centralized approach however, is that a fusion center becomes very critical; making its failure rue the whole concept of cooperation.

Unlike the centralized, in distributed approach for cognitive radio cooperative spectrum sensing, no one node act as fusion center (FC) or central processor controls. Instead communication exists between the different nodes and they are able to share sense information. As proposed by Roozgard *et al.,*(2012). A distributed sensing method where secondary users share their sensing information among themselves was proposed in Ghasemi and Sousa (2005), A distributed cognitive radio architecture for spectrum sensing is given by Gandetto *et al.,* (2005), Gandetto and Regazzoni (2007). However, the various methods proposed for the application of distributed detection consist of numerous iterations in accomplishing unanimous cooperative decisions, with substantial network information overhead and bandwidth consumption, while increasingly being too complex to implement, thus not aligning with the opportunistic access to spectrum bottom line. It also need individual radios to have a much higher level of autonomy, and possibly setting themselves up as an ad-hoc network.

Besides centralized and distributed cooperative sensing, the third scheme is relay assisted cooperative sensing. As proposed by Atapattu *et al.*,(2011) a theoretic detection performance of an energy detector is considered for channels encountering both multipath fading and shadowing. The relay-assisted detection paradigm provides a scheme where an SU serves as a relay, forwarding sensed information. In the work of Roozgard *et al.*.(2012), the centralized and distributed schema is considered a one-hop cooperation, while the relay-assisted approach is thought of as a multi-hop cooperative scheme.

Another sensing technique considered under this review is the wavelet based detection. It is widely used technique in image processing for edge detection applications. Tian and Giannakos (2007) have proposed this approach in spectrum sensing where wavelets are used for detecting edges in the power spectral density (PSD) of a wideband channel. The edges in power spectral density are the boundary between spectrum holes and occupied bands and hence it helps to find vacant bands. Based on this information CR can identify the spectrum opportunities.

Waveform based sensing was also considered as proposed by Tang (2011), Sahai *et al.*,(2006), Mahadevappa *et al.*,(2007). This method is only applicable to systems with known signal patterns which could be preambles, regularly transmitted pilot patterns, spreading sequences and etc. It is termed as waveform-based sensing or coherent sensing. It is shown by these authors that waveform based sensing outperforms energy detector based sensing in reliability and convergence time. Furthermore, it is shown that the performance of the sensing algorithm increases as the length of the known signal pattern increases.

This dissertation review also considered radio identification based sensing as proposed by Kang *et al.,* (2011). This method veers from the typical study of interference which is usually transmitter-centric. Typically, a transmitter controls its interference by regulating its output transmission power, its out-of-band emissions, based on its location with respect to other users. Cognitive radio identification based detection concentrates on measuring interference at the receiver. Their model accounts for cumulative radio frequency energy from multiple transmissions and sets a maximum cap on their aggregate level. As long as the transmissions of cognitive radio users do not exceed this limit, they can use a particular spectrum band. The major hurdle with this method is that unless the cognitive user is aware of the precise location of the nearby primary user, interference cannot be measured with this method. An even bigger problem associated with this method is that it still allows an unlicensed cognitive radio user to deprive a licensee (primary user) access to his licensed spectrum. This situation can occur if a cognitive radio transmits at high power levels while existing primary users of the channel are quite far away from a receiver and are transmitting at a lower power level.

The work also considered review of some optimization work done under cognitive radio and some artificial intelligence techniques.

The concept of a time-spectrum block was introduced by Devroye *et al.,*(2006), this technique represented the time for which a cognitive radio uses a portion of the spectrum, which was used to define the spectrum allocation problem as the packing of time spectrum blocks in a two dimensional time-frequency space, such that the demands of all nodes are satisfied best possible Lassila and Penttinen (2009) affirmed. The associated optimization problem is NP hard for which an approximation algorithm is given that assumes full knowledge of user demands. The algorithm performs within a small constant factor of the optimum, regardless of network topology. In their optimization approach distributed solution and b-SMART is given which only utilizes local information, which is able to achieve high throughput and fairness under various scenarios.

Chowdhury and Akyildiz (2008), proposed an optimization framework which is derived for nodes equipped with a single tunable transceiver to monitor the primary channels while continuing operation in the secondary band. The sensing problem is addressed by formulating the task of sensing as a linear programming problem based on received signal strength values on any given channel. For evaluating the impact of using a particular free channel, an analytical model is derived for estimating interference caused at any arbitrary location and frequency. The channel assignment is formulated as an optimization problem that is solved at each user using the empty channels identified through sensing and analytical power estimations.

The graph-theoretic model as proposed by Chunyi *et al.*,(2006), was developed to describe efficient and fair access by using three different policy-driven utility functions. It is shown that the optimal spectrum allocation problem can be reduced to a variant of the graph coloring problem (NP-hard). Subsequently, a lower bound on the maximal utilization problem where fairness is not considered is proven. Finally, a vertex labeling mechanism is described that can be used to construct both centralized and distributed approximation algorithms. The game theoretic objective was to reach the Nash Equilibrium where no user can get utility benefit by changing its own allocation strategy alone. In the work of Thoppian *et al.*, (2006), a graph-theoretic optimization formulation was derived for the channel allocation problem and a heuristic distributed algorithm is proposed for solving it. However, in their work no bounds or approximations were derived.

An optimization problem is formulated with the objective of minimizing the required network-wide radio spectrum resource for a set of source-destination pair rate requirements as proposed by Hou *et al.*,(2008). Special attention was given to modeling of spectrum sharing and unequal (non-uniform) sub-band division, scheduling and interference modeling, and multipath routing. The resulting formulation is a mixed-integer non-linear program (NP-hard). For this novel lower and upper bound approximation schemes were derived, which yield an accurate characterization of the optimum.

In the work of Shi and Hou (2008), an optimization formulation was derived for maximizing data rates for a set of user communication sessions by jointly considering power control, scheduling, and routing. The problem results in a mixed integer nonlinear programming formulation for which an accurate upper bound is derived. Finally, a distributed optimization algorithm is developed that iteratively increases data rates for user communication sessions, which is able to achieve a near-optimal performance.

Another channel allocation formulation is given in the work of Miao and Tsang (2008). However, no bounds/approximations or distributed solutions were considered.

Deka *et al.,* (2012), proposed optimization of spectrum sensing in cognitive radio using genetic algorithm (GA). Here they used genetic algorithm (GA) for the best possible space allocation and also for spectrum reuse. Two criteria were fulfilled – one of which was the maximization of the probability of detection and the other minimization of false alarm in spectrum hole detection. Though it is found that with the help of genetic algorithm the optimized result is better than without using genetic algorithm. It is necessary that the secondary user should vacate the spectrum in use when licensed users are demanding and detecting the primary users accurately by the cognitive radio. This approach lack some merit due to inability to sense accurately the arrival of the primary users and which channel to allocate to the secondary user.

Optimal channel sensing/probing strategies for opportunistic spectrum access were analyzed by Chang and Mingyan (2008). In the considered setting a transmitter seeks to maximize its achievable data rate by opportunistically transmitting over a select subset of a potentially large number of channels. Due to constraints on time, energy, and other resources, a transmitter may only be able to probe a limited number of channels. Methods from competitive analysis have been applied to design strategies that perform well in the worst case. For this a class, optimal randomized strategies are derived. The analysis uses probabilistic techniques characterizing the random nature of the wireless environment. However, there are no stochastic components in the analysis. Also, an algorithm that constructs a strategy belonging to this optimal class is derived. The interaction between primary and secondary users was not modeled.

The review also took into consideration Stochastic Models Approach of Optimization. Stochastic models refer to the dynamic models where the state of the channel (especially, due to primary user reservation) varies randomly in time (Lassila and Penttinen, 2009). Within these models the research aims generally at maximizing the total throughput or utility of the secondary users under some constraints that make the problem interesting. Typical constraints include constrained sensing ability, limited channel availability information and delays in channel sensing. Constraints can also take a more abstract form which was demonstrated in the work of (Vartika and Nitin, 2007), they considered a random (c, f) assignment in which channel switching was constrained so that each node was assigned a random f-subset of channels from the c available channels.

Stochastic considerations are commonly associated with MAC protocol development for the secondary users.

Felegyhazi *et al.*,(2007) considered a model where communicating pairs of nodes share a single collision domain. In their model each node has a number of radio devices which it can allocate to a set of channels. Multiple devices can be assigned to the same channel but the total rate of the channel can decrease as more devices access it. The authors show that despite the non-cooperative nature of the users (each trying to maximize its own rate) the solution converges to a load balancing solution. Algorithms are also provided for achieving this solution under different sets of available information. Wang *et al.*,(2010) took a more information theoretical approach to resource sharing. They model explicitly SINR dependent transmission rates and power allocation of non-cooperative rate-maximizing users over multiple channels. They show that the solution converges to Nash equilibrium in a price-based iterative water-filling algorithm, which can also be used in a distributed fashion. The authors also present a protocol to implement their scheme.

Scaling laws for the performance of cognitive networks have been derived in the work carried out by Mai *et al.*,(2007), Mitran (2008) and Devroye *et al.*,(2008). In their research only single-hop connectivity has been assumed and the focus is on characterizing the scaling behavior of the interference of the secondary users on the primary users. They consider a cognitive network consisting of n randomly located pairs of cognitive transmitters and receivers communicating simultaneously in the presence of multiple primary users. Assuming single-hop transmission it is shown that, with path loss exponent larger than 2, the cognitive network throughput scales linearly with the number of cognitive users. Additionally, bounds are obtained on the required radius for a primary user so that within this radius no cognitive user may be active in order to achieve a given outage probability for the primary user. This method is considered useful if at least one node could transmit while maintaining its interference to the primary users below a given threshold. The results characterize the limiting behavior between the threshold, outage probability and the number of secondary users.

Simulated annealing (SA) and genetic algorithms (GA) can deal with multidimensional optimizations where traditional numerical methods might not be fast and scalable enough if applied to the full dataset. This method was proposed by Petrova *et al.,* (2006), Simulated annealing examples were shown in the work of Kirkpatrick *et al.,* (1983) and Cerny (1985). These examples belong to the random (adaptive) search algorithms where a random walk through the solution space governs the search towards an optimal solution. It mimics the natural processes of controlled cooling of a material. SA algorithm frequently avoids local minima by accepting, with some probability, also changes in the search space that worsen the objective function score. This probability is proportional to the “temperature” control parameter that decreases as the algorithm proceeds. There are also adaptations that improve the performance of the algorithm. The advantage of SA is that it is a simple and highly efficient method for finding the optimal or acceptably good solution, which can be combined with other methods to improve the final result. However, initial parameters of the algorithm should be carefully chosen for an effective search.

Hidden Markov Models (HMMs) was a convenient and mathematically tractable statistical model which was developed in order to describe and analyze the dynamic behavior of a complex random phenomenon that can be modeled as a markov process with observable and unobservable state. This method was proposed by Tsagkaris and kalidiotis (2008), Bae *et al.,*(2010), Tan *et al.,*(2013). The proposed technique can dynamically select different licensed bands for its own use with significantly less interference from and to the licensed users. This technique has the capability of predicting based on experience. Also it is easily scalable, excellent for classification and can be used to model complex statistical processes. The HMMs has the following drawbacks: It requires a good training sequence and it is computationally complex. The accuracy of the prediction was not provided in their work. It only deals with deterministic traffic scenarios, but it is not applicable for the actual environment. Determining an optimal model in HMMs is difficult, it requires a large memory space to store the past observations and high computational complexity for estimation of model.

A metaheuristic algorithm is used in cognitive radio to search through a solution space while learning and establishing the requisite relationships in computationally hard problem. One of the types of metaheuristic algorithm called tabu search was used in the work of Newman *et al.*,(2010). The technique is good in optimizing parameters, it can be easily implemented, the performance of the search method is enhanced by using memory structure called tabu list which ensures that a recent move is not repeated or reversed. However, the formulation of rule space is difficult if optimization or learning is not restricted.

Also Ant colony optimization (ACO) was used in the work of Dorigo and Blum (2005). The ACO mimics ant behavior walking around a graph representing the problem to be solved and finding locally productive areas. Though it is easy to adapt to real time change however, it is not efficient for local searches.

The artificial neural network (ANN) which is a set of nonlinear functions with adjustable parameters to give a desirable output was also considered under this review. There are different types of ANNs which are separated by their network configurations and training methods which facilitates a multitude of application. A radial basis function networks (RBFNS) used in the work of He *et al.,* (2010) has built-in distance criterion with respect to a center in its hidden layer. This prevents the network from settling into local minimal which is a major challenge peculiar to perception networks. The multi-layer linear perception networks

(MLPNs) type of ANN was used in the work of Aibinu *et al.*,(2010), (Aibinu and Salmi, 2011). This network is made up of layers of neurons where each neuron is a linear combination of the previous output. The size of the network and application determine the performance of the training algorithms. A multilayer nonlinear perception networks (NPNs) type of ANN was used in the work of Baldo and Zorzi (2008). This network which enables the incorporation of non-linearity in the network provides highly flexible and dynamic results. However, the use of back propagation for training resulted in more processing time needed to achieve a precise result; consequently, it is slow to converge during training.

This review also considered authors that have applied the ANNs and pointed out the drawbacks:

Feng *et al.,* (2012), proposed a statistical mean throughput as evaluation criteria for cognitive user with fixed rate service in spectrum sensing. In his work it was assumed that the state of vacancy and occupancy time of objective license channel are independent of each other with exponential distribution. Furthermore, it was also reported that N objective license channels is being predicted based on the result of machine learning at each time slot. The cognitive user with fixed rate service based on machine learning spectrum sensing has better performance compared to random spectrum sensing. Also, there is decrease in packet loss rate as the channel time detection threshold increases. However, there is decrease in effective transmission time and difficulty is encountered in determining an appropriate method of increasing the sample size for the statistical mean throughput since it is impossible that the sample size tends to infinity.

ANN-based signal classifier was developed in the work of Fehske *et al.*,(2005). It utilizes the extracted cyclostationary signal features which is a new method for classification of communication signals based on cycle spectral analysis and pattern recognition performed by a neural network. In this work two cases were studied: Classification with and without prior knowledge of carrier and bandwidth of the signal. Distinct features of each signal type were extracted using cyclic spectral analysis and neural network was designed to classify signals based on these features. The combination of the cyclstationary analysis and ANN provides an efficient and reliable signal classification. The strength of this approach was in the reduction of the online processing time. Also it provides an efficient and reliable signal classification and is robust to stationary noise. However, difficulty is encountered in comparison due to the practical limitations of the number of modulation type analyzed. Furthermore, there were no consideration for scenarios where two or more signals such as BPSK, APSK, FSK etc being present.

Luo *et al.,* (2010) proposed a biconvex optimization approach for spectrum sensing in cognitive radio networks. They formulate a joint optimization problem regarding both the sensing threshold and the number of sensing samples in the energy detector, to minimize the average detection time of an available channel. In their proposal they proved that it can be transformed into a biconvex problem under practical conditions. Numerical results show that the proposed optimal approach can significantly decrease the mean time to detect a spectrum hole.

Liang *et al.,*(2008), proposed an optimal sensing duration in order to maximize achievable throughput of the secondary network. Later, the authors extended this single frame optimization approach over multiple slots.

Rondeau *et al.,*(2014), presented a technique that can be used in adjusting radio parameters. In the technique an adaptation mechanism that uses genetic algorithm GA to optimize the radio parameters on the physical layer was proposed. The GA is used to realize cross layer optimization and a method of adaptive waveform control. It is referred to as the Wireless System Genetic Algorithm (WSGA) by the author. The advantage of this technique is that it has a dynamic fitness definition and evaluation where the weighting of each function is adjustable. Also, it has the capability of enabling any fitness function to be used as required but the current link conditions and user requirements. Furthermore, it has the capability of applying constraints to the optimization problem which facilitated the incorporation of regulatory and physical restrictions during chromosome evolution and the WSGA is capable of working with real hardware to accomplish real goals. However, this method has the following drawbacks – the use of proxim tsunami radios which has a limited number of adaptable parameter for experiment is a great disadvantage. Also the convergence speed of the system is slow and there is no assurance that the winning member after all the single comparisons in all dimension are the best or non dominated member of the population.

Baldo and Zorzi (2008), proposed multilayered feed forward neural networks as an effective technique for real-time characterization of the communication performance. This provide a general-purpose black box modeling (this consists of analyzing input-output relations of the system under consideration, and trying to build a predictor with the purpose of estimating output values for unknown combinations of inputs) of the performance as a function of the measurements collected by the cognitive radio thus providing good modeling accuracy. Also, it is flexible and as such can be used for runtime modeling in different applications and scenarios and no prior knowledge of the laws driving the real system is required. Furthermore, it avoids all assumptions which are not verifiable in practice and has the ability to account for non-idealities in parameters i.e. tolerance of components, device failure, etc. However, a great drawback is how to effectively determine the values of the weights and biases which will provide the desired approximation for arbitrary continuous functions defined over compact subsets during training. Also, additional effort and time is needed in training the multilayered feed forward neural network (MFNN) when adding a new variable to a MFNN performance predictor.

Mathad and Sarvagya (2013), proposed a cross layer approach in handling cognitive radio challenges. In their proposal, they used merging approach, streaming approach and parallel approach. In all of these approaches there was no optimal reality of the cognitive radio characteristics.

Najashi *et al.,* (2013), proposed a neural network based prediction model for predicting the channel status using historical data obtained during a spectrum occupancy measurement. Genetic algorithm with LM BP was combined for increasing the probability of obtaining the best weights thus optimizing the network. The results indicate high prediction accuracy over all bands considered but their proposal was based on probability prediction that may result to uncertainty.

Some other researchers like Akbar and Tranter (2007), Park *et al.,*(2007), Tumuluru *et al.,*(2010) also proposed prediction model but most of these works employ Markov chains for the prediction problem and assumed that the primary user traffic follows a Poisson process. Jianli *et al.,*(2011) proposed a neural network based spectrum prediction using Multilayer Perceptron MLP. An hour long data was divided into 60 slots and converted into a time series. This was used to train and test the network.

Liang *et al.,*(2011) proposed a practical spectrum behavior learning method based on MLP artificial neural network (ANN). Here performances were evaluated with an existing 7-day spectrum data set from a previous measurement, which was conducted in a metro city located in south China.

Koufos (2013), suggested some interference control and power algorithms that may govern the operation of the database. The result shows that the traditional signal detection framework is not appropriate for recovering transmission opportunities in the spatial domain and proposed alternative model.

Tsagkaris *et al.,*(2008), in his work focused on the channel estimation and predictive phases where a benchmarking work that aims at evaluating the applicability of multiple types of neural networks (NNs) in the learning module of the cognitive engine within a cognitive terminal was developed. The proposed neural network (NN) based learning schemes relax the reasoning process and assist in the optimum decision regarding the radio configuration settings (mainly PHY and MAC layer) that provides the best QoS for the given problem and user application needs. A potential solution is proposed that assists the cognitive radios in the derivation and enforcement of decision regarding the selection of desired radio configuration which will optimize its QoS. However, this proposed scheme has the following drawbacks; the assumption that the NN-based scheme should be tuned in an arbitrary radio configuration is a major drawback of this technique. Also, there may be overtraining or over fitting of the training data as a result of the network not been properly trained which may lead to the network not learning the basic structure of the data but instead learning irrelevant details of the individual cases. In addition to this, a realistic input time series and environment situations are not considered; this may affect the NN-based schemes validity and robustness.

Hamid (2013), proposed an interference tolerance driven spectrum opportunities as a methodology for building a geolocation database for spectrum opportunities. His methodology is based on allowing secondary operation as long as the interference caused by it is below a certain limit specified by the primary user requirements.

Zurutuza (2011), made a theoretical studies related to cognitive radio and TV white space communications, focusing on current activities, standardization processes, commercial approaches and related dissertations. Also he analyzed the background and the present TV white space communications status. Also the geolocation database system that addresses the main requirements for proper TVWS detection and primary users' protection was considered. The result of this proposal did not tackle the interference situations that may arise between the primary users and secondary users.

Po-Kai *et al.*, (2012) proposed a lagrangean relaxation based heuristic (LRH) to jointly consider channel assignment, power allocation, and routing to minimize network energy consumption in the cognitive radio networks. Such cross-layer design problem has been completely formulated as a mixed integer non-linear programming (MINP). The simulation results indicate that the proposed LRH outperforms the two approaches and obtains a significant power gain but not in totality

Fotis (2012), proposed a cross-layer opportunistic spectrum access and dynamic routing algorithm for cognitive radio networks is proposed, called ROSA (Routing and Spectrum Allocation algorithm). Through local control actions, ROSA aims at maximizing the network throughput by performing joint routing, dynamic spectrum allocation, scheduling, and transmit power control. Lee et al., (2010) proposed the cross layer design approach and challenges for cognitive radio functionalities to enhance its efficiency in dynamic spectrum access management. Spectrum sensing and scheduling challenges as well as spectrum shaping challenges are described for the implementation in cross layer design in their approach. Appropriate techniques in enabling multimedia application over cognitive radio were addressed.

This work however, made analysis in four locations for the availability of TVWS and used the geolocation technique to create database that will be accessed in a real time basis for exchange of relevant information to secondary users and switch the secondary users to unused portion of the spectrum. The work first of all x-rayed the behavior of primary users signal by simulating the transmitting infrastructures in the geographical location under review. Genetic algorithm and rule based system were used to optimize the channel selections for WSD usage under strict conditions that formed the knowledge base. The work also considered interference avoidance with the primary user. The earlier aforementioned problems in this work were systematically considered and solutions were provided.

2.3 Summary of Review

The concept of electromagnetic spectrum was first considered and different frequency bands for low frequency were shown. Also the radio spectrum was x-rayed with its applications in different domain of life. Processes for spectrum allocation were also presented. In section 2.2 different literature on techniques used for sensing the spectrum holes were reviewed. The sensing techniques among others considered include energy detector based also known as radiometry or periodogram which is seen as the most common way of spectrum sensing because of its low computational and implementation complexities. Matched filter which is a linear filter designed to maximize the output signal to noise ratio for a given input signal. Cyclostationary feature detection is another method which exploits the periodicity in the received primary signal to identify the presence of Primary Users (PU). Others include interference based detection, cooperative sensing detection, wavelet based detection. The methods reviewed are characterized with so many challenges which include uncertainty in detection of actual locations of the white spaces, assumption of the primary user in relation to the secondary user, also assumption of the existence of white spaces. High sensing time and complicated signal processing algorithms is required.

However, this research work was able to overcome most of the shortcomings in the reviewed existing work which ranges from non analysis of the existence of white spaces before proposing algorithm for allocation. Majorly, the analyzed works in the literature above did not provide means of overcoming interference between the primary and secondary users which is a major setback. This dissertation used rule based system to create the best ways of allocating the available white spaces to demanding white space devices with minimal or no interference situation. Considering the best fit channel before allocation of white spaces for quality of services were not considered in the review literatures which is a major problem in communication. This work used genetic algorithm not only to optimize usage but also optimize fitness of the channels before allocation. The work modified genetic algorithm by applying a non mutation scenario to avoid flipping of the bits in order to achieve the desired task of this work. The developed program in this research work was able to sense the presence of white spaces, allocate same to users without causing interference to the primary users. Also misdetection and false detection of white spaces associated with most work in the reviewed literature was overcome by our program.

CHAPTER THREE

METHODOLOGY AND SYSTEM ANALYSIS

3.1 Methodology Adopted

A methodology is a system of methods and principles used in a particular “school” of design. It can also be seen as a system of converting an input into an output. The Object Oriented Development Methodology was used in this work because we live in a world of objects. These objects exist in nature, in man-made entities, in business, and in the products that we use. They can be categorized, described, organized, combined, manipulated and created. Therefore, an object-oriented view has come into picture for creation of computer software. An object-oriented approach to the development of software was proposed in late 1960s. Object-Oriented development requires that object-oriented techniques be used during the analysis and implementation of the system. This methodology demands that the analyst should determine what the objects of the system are, how they behave over time or in response to events, and what responsibilities and relationships an object has to other objects. Object-oriented analysis requires the analyst look at all the objects in a system, their commonalties, difference, and how the system needs to manipulate the objects. The Object Oriented Methodology of Building Systems takes the objects as the basis. For this, first the system to be developed is observed and analyzed and the requirements are defined as in any other method of system development. Once this is done, the objects in the required system are identified. For example in case of a Banking System, a customer is an object, a cheque book is an object, and even an account is an object.

A prototype is an original type, form, or instance of something serving as a typical example, basis, or standard for other things of the same category. In many fields, there is great uncertainty as to whether a new design will actually do what is desired. New designs often have unexpected problems. A prototype is often used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theories and confirm performance prior to starting the production of a new product. It is these reasons that this methodology was adopted in this work.

3.1.1 Justification for the Methodologies Adopted

Due to the nature of this research work more than one design methodology was adopted. The methodologies adopted in this work are the object oriented methodology and Prototype methodology. The essence is to benefit from different capabilities and be able to come out with a good system. The benefits include among others the following:

(i) The system being developed in this study consist of objects and real world requirements, thus the best suitable methodology that will bring out the best of the system is the Object Oriented Development Methodology.

(ii) Technological innovations will continue to lead to development of new devices that will communicate with existing ones. Thus, this study adopted the Object Oriented Development Methodology because it encourages more re-use. New applications can use the existing modules, thereby reduces the development cost and cycle time.

(iii) Identification of any problem with efficacy of earlier design requirements analysis and coding activities is considered very essential with the nature of this study. Also since it will be necessary test various aspects in order to obtain quick feedback from the users, the prototype methodology were considered appropriate for this work.

3.2 Materials Required

In the cause of carrying out this research work, both hardware and software materials were used.

Hardware Materials

The hardware materials used in carrying out this work include the following:

Digital Video Broadcasting – DVBT (Standard) and Digital Video Broadcasting – DVBT-2 (second generation terrestrial). DVB-T is a technical standard, developed by the DVB Project, which specifies the framing structure, channel coding and modulation for digital terrestrial television (DTT) broadcasting.

Anritsu Ms2711A Spectrum Analyzer was also used as another measurement tools, it measures the magnitude of an input signal versus frequency. Its primary use is to measure the power of the spectrum of known and unknown signals. It also displays RF signals from base stations and other emission sources. They find rouge signals, measure carriers and distortion, and verify base stations. Unlike a power meter, they validate carrier frequency and identify desired and undesired signals.

Software Materials

The software tools used in this research work include:

Hypertext Preprocessor (PHP)

Cascading Style Sheet (CSS)

JavaScript and

Hypertext Mark-up Language (HTML)

3.3 The Organization and Her Environment

The organization used in carrying this research Metrodigital limited, it is a leading cable pay TV company in Nigeria with branches in various states of the federation. The company is mainly into Entertainment, Fabrication, satellite & cable tv and offering Cable Television, Satellite TV Cable Maintenance, Decoder Installation etc.

3.4 System Analysis

Generally, System analysis refers to process through which an existing system is examined with the intent of improving it or creating a new system, through better procedures and methods.

3.4.1 Analysis of Existing System

In this section, the existing system has been analyzed. The aim is to find out its behavioral characteristics, short comings, challenges so as to improve on it. Analysis of existing system is essential because it exposes the behavioral pattern of the system. In this dissertation the existing system which is the TV white space is analyzed to show its characteristics.

The VHF and especially the UHF bands are highly attractive to newer technologies because lower frequencies are affected more by atmospheric noise and interference from electrical equipment. Higher frequencies are also susceptible to attenuation making the UHF band very competitive and highly desirous for radio communication. Though the radio spectrum is a natural resource which can be reused, it can only accommodate a limited number of simultaneous users. Therefore, if the competition for the UHF band is left unmanaged, congestion of the band may result and this can lead to harmful interference that can degrade signals or interrupt communication services. The problem of limited spectrum is further compounded by the development of new technological innovations that must be encouraged through the availability of suitable spectrum.

The VHF and UHF band, sometimes referred to as the television broadcast band, has been primarily used for terrestrial television broadcast services. However, there are several spaces within these spectrum bands that are not used by licensed television services in Nigeria. These holes are often referred to as Television (TV) White Spaces. The term White Space is used to describe a part of the frequency spectrum which is available for radio communication at a given time, in a given geographical area on a non-interfering and non protection basis with regard to other services.

The sub-band 474 – 866 MHz in the Ultra High Frequency (UHF) band (i.e. Channel 21 – 70) is allocated primarily for terrestrial TV broadcasting service on a worldwide basis. In traditional radio system planning, co-channel TV broadcasting stations and hence their coverage areas are geographically separated so as to avoid radio interference. As a result, some TV channels at certain locations are not used at all times. These TV channels are generally referred to as TVWS or TVWS spectrum".

This dissertation design process decided to exploit the sub-band of 474MHz to 866MHz UHF representing channels 21 to 70 to determine the availability of TVWS in some selected geographical areas for possible deployment of low power telecommunications applications, such as wireless broadband Internet access and machine-to-machine ("M2M") applications (e.g. smart metering). The analysis shows that there are relatively high percent of TVWS availability in the area under consideration.

3.4.2 Analysis of the Existing Models

a) Energy Detector Based Model

Energy detector is a non-coherent method of spectrum sensing and it is used in detecting the primary user signal in the frequency spectrum being sensed. Energy detection sensing method is more popular because it does not require any prior information of primary signal and it is simple.

Let us define the signal model used in the energy detector model. H_0 and H_1 are two hypotheses and they are used to represent the presence and absence of a radio signal, the corresponding signal model is given by

$$r(t) = \begin{cases} V(t); \text{ under } H_0 \\ H_s(t) + V(t) \text{ under } H_1 \end{cases} \quad (3.1)$$

where $r(t)$ is the complex baseband of the sensed radio signal, $s(t)$ is the received primary user signal, and $v(t)$ is the additive bandlimited complex Gaussian noise with a noise power of σ^2 (including the real and imaginary noise components) over a bandwidth of Bw (Hz). The channel component h has an amplitude and phase shift associated with it given by $h = \alpha\angle\theta°$. Various models can be adopted for the received radio signal $s(t)$ without the noise component, depending on the considered wireless channel. The fundamental nature of spectrum sensing is a binary hypothesis-testing problem.

H_0: primary user is absent

H_1: primary user is in operation

In this section, consideration of different channel models was presented with their corresponding detection performances. The general block diagram for energy detection is shown in figure 3.1.

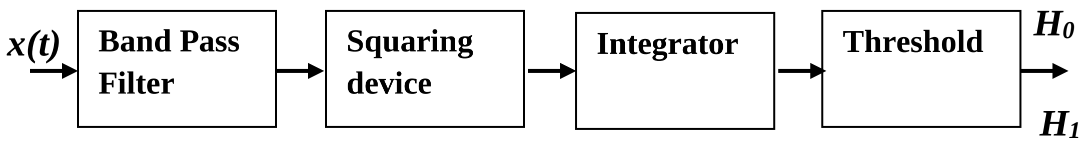


Figure 3.1: Block diagram of energy detection **(**Mohamad and Sani 2013).

Based on Figure 3.1 the input signal *x(t)* is filtered with a band pass filter in order to limit the noise and to select the bandwidth of interest. The noise in the output of the filter has a band-limited, flat spectral density. The power, *Y* from integrator is then compare with threshold value to examine the two hypotheses *Ho* and H_1

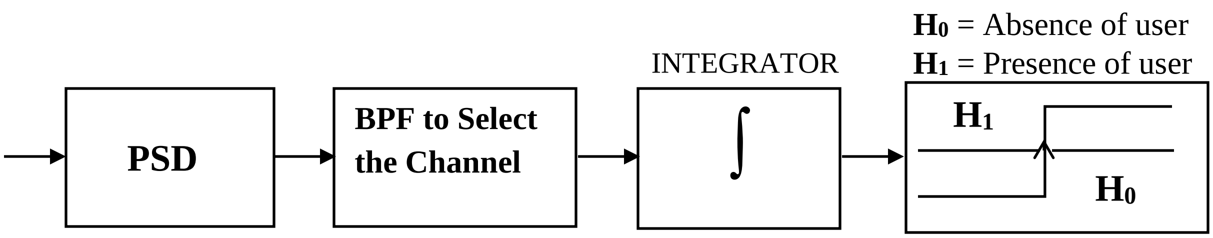


Figure 3.2: Modified block diagram of energy detection **(**Shahzad 2010).

The modified block diagram for the energy detection technique is shown in Figure 3.2. The signal passes through the power spectral density (PSD) unto the band pass filter (BPF) of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions.

The energy detection techniques is said to be blind signal detector because it ignores the structure of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold v derived from the statistics of the noise. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test,

$$y(k) = n(k) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots H_0$$
$$y(k) = h * s(k) + n(k) \ldots\ldots\ldots\ldots\ldots\ldots H_1 \qquad 3.2$$

Where y (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance σ^2.

Let y (k) be a sequence of received samples k ∈{1, 2….N} at the signal detector, then a decision rule can be stated as,

$$H_0 \ \ldots\ldots \ if \in \ < v$$
$$H_0 \ \ldots\ldots \ if \in \ > v \qquad 3.3$$

Where $\in = E\,|y(k)|^2$ the estimated energy of the received signal and v is chosen to be the noise variance σ^2.

Drawbacks of Energy Detector Based Method

Though, it is a non coherent detection method that detects the primary signal based on the sensed energy. Due to its simplicity and no requirement of a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing. The following are the challenges faced by this method:

(i) The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor, or it can be said that the decision threshold is subject to changing signal-to-noise ratios.

(ii) Energy detection cannot be used to distinguish primary signals from the CR user signals. As a result CR users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing technique

(iii) It has poor performance under low signal-to-noise ratio (SNR) value.

(iv) Energy detectors do not work efficiently for detecting spread spectrum signals

(v) High sensing time is taken to achieve a given probability

(vi) Its detection performance is subject to the uncertainty of noise power.

(vii) The energy threshold used for detection at the detector by the existing system is highly susceptible to unknown or varying noise power levels and threshold values need to be adjusted adaptively.

(viii) Under frequency selective fading, deciding energy threshold value is difficult with channel notches and sophisticated mechanism should need to be employed.

(ix) It requires more complicated signal processing algorithms in order to work with spread spectrum signals like direct sequence and frequency hopping,.

(x) The existing system cannot differentiate between modulated signals, noise and interference and hence, therefore, cannot benefit from interference cancellation techniques.

(xi) The existing system requires perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format.

b) Matched Filter Model

The matched filter detection based sensing is exactly the same as the traditional matched filter detection technique deployed in digital receivers. Obviously for match filter based spectrum sensing a complete knowledge of the primary user signal is required (such as the modulation format data rate, carrier frequency, pulse shape, etc).

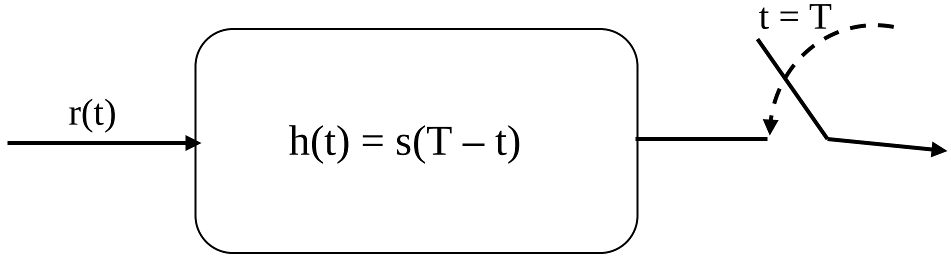


Figure 3.3: Matched filter based spectrum sensing Model for detecting primary users. (Cabric et al.2006)

The fundamental results on matched filter detection are presented in this section. Given a real transmit signal waveform $s(t)$ defined over $0 \leq t \leq T$ the corresponding matched filter maximizing the signal to noise ratio at the output of the filter sampler is given by

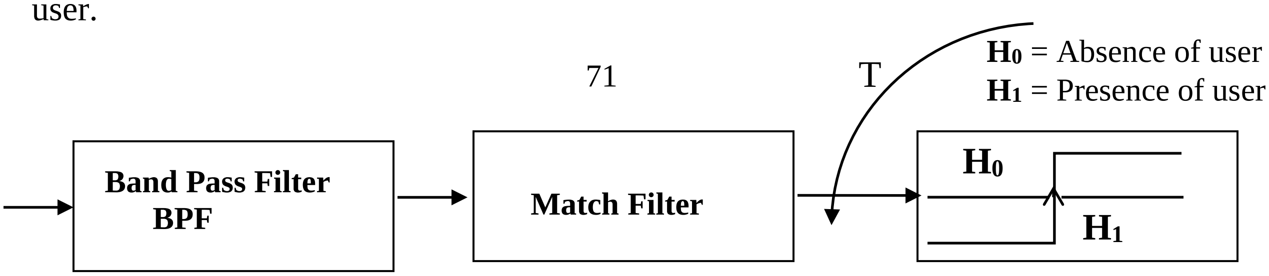
$$h(t) = \begin{cases} s(T-t); & 0 \leq t \leq T \\ 0; & elsewhere \end{cases} \quad (3.4)$$

Figure 3.3, depicts matched filter based spectrum sensing method for primary user detection. Then based on the test statistic $\xi(nT)$ at the output of the filter sampled every $t = nT$ seconds, the detector is given by

$$d(nT) = \begin{cases} 0; & \xi(nT) < \lambda \\ 1; & \xi(nT) \geq \lambda \end{cases} \quad (3.5)$$

The matched filter-based detector requires complete signal information and needs to perform the entire receiver operations (such as synchronization, demodulation, etc.) in order to detect the signal.

Figure 3.4, shows the explicit model for match filter technique, initially the input signal passes through a band-pass filter; this will measure the energy around the related band, then output signal of BPF is convolved with the match filter whose impulse response is same as the reference signal. Finally the matched filter out value is compared to a threshold for detecting the existence or absence of primary user.



The operation of matched filter detection is as expressed in equation 3.6 below.

$$Y(n) = \sum_{K=-\infty}^{\infty} h(n-k)\, x(k) \qquad 3.6$$

Where x is the unknown signal (vector) and is convolved with the h, which is the impulse response of matched filter that is matched to the reference signal for maximizing the signal to noise ratio (SNR). Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users .

C. Cyclostationary Feature Detection Model

A cyclostationary process is a signal having statistical properties that vary cyclically with time, it can be viewed as multiple interleaved stationary processes. These processes are not periodic function of time but their statistical features indicate periodicities. The following conditions are essential to be filled by a process for it to be wide sense cyclostationary. A random process $x(t)$ is classified as a wide sense cyclostationary process if the mean and autocorrelation are periodic in time with some period T, given by

$$E_x(t) = E_x(t + mT) = E[x(t)] \qquad (3.7)$$

and

$$R_x(t, \boldsymbol{\tau}) = R_x(t + mT, \boldsymbol{\tau}) = E[x(t)\tilde{x}(t + \boldsymbol{\tau})] \qquad (3.8)$$

$\tilde{x}(t)$

where, t is the time variable, t is the lag associated with the autocorrelation function, is the complex conjugate of $x(t)$, and m is an integer. The periodic autocorrelation function can be expressed in terms of the Fourier series given by

$$R_x(t, \tau) = \sum_{\alpha=-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(2 = \pi j \alpha t) \qquad (3.9)$$

where

$$R_x^{\alpha}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_T x(t + \frac{\tau}{2}) \tilde{x}(t - \frac{\tau}{2}) \exp(-2\pi j \alpha t) dt \qquad (3.10)$$

The expression in equation 3.10 is known as the cycle autocorrelation. Using the Wiener relationship, cyclic power spectrum (CPS) or the spectral correlation function can be defined as:

$$S_x^{\alpha}(f) = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(-j2\pi f \tau) d\tau \qquad (3.11)$$

The CPS in (3.11) is a function of the frequency f and the cycle frequency α and any cyclostationary features can be detected in the cyclic frequency domain a property that is exploited to be used as a spectrum sensing technique. An alternative expression for (3.10) for the ease of computing the CPS is given by

$$S_x^{\alpha}(f) = \lim_{T_0\to\infty} \lim_{T\to\infty} \frac{1}{T_0 T} \int_{-T_0/2}^{T_0/2} X_T(t, f + \frac{1}{\alpha}) \tilde{X}_T(t, f - \frac{1}{\alpha}) dt \qquad (3.12)$$

Where $\tilde{X}_T(t, u)$ is the conjugate of $X_T(t, u)$, and $X_T(t, u)$ given by

$$X_T(t,u) = \int_{t-T/2}^{t+T/2} x(v) \exp(-2j\pi u v) dv \qquad (3.13)$$

Expression in (3.12) is also known as the time-averaged CPS, which achieves the theoretical CPS when computed over a sufficient number of samples.

In order to use the cyclostationary features to perform spectrum sensing in wireless communications, the hypothesis equation for the presence of a primary user signal can be re-written considering the CPS as

$$H_0:\ S_r^{\alpha}(f) = S_v^{\alpha}(\mathrm{f})$$

$$H_1:\ S_r^{\alpha}(f) = S_s^{\alpha}(f) + S_v^{\alpha}(f) \qquad (3.14)$$

Where, $S_v^{\alpha}(f)$ is the CPS of the additive noise *u*(*t*), and $S_s^{\alpha}(f)$ is the CPS of the primary user signal *s*(*t*). Since *v*(*t*) is not a cyclostationary process, the CPS of *v* for $\alpha \neq 0$ is zero.

D. Wavelet Model

Wavelet Based Spectrum Sensing Waveform Based Spectrum Sensing method is applicable when the system known signal patterns only. These known pattern are used for synchronization. This pattern includes preambles, spreading sequences, midambles etc. Waveform Based Spectrum Sensing is more reliable and robust than other method. This method does not require any prior information of the system.

Table 3.1: Comparison of Various Methods Analyzed

PARAMETER	**ED**	**MFD**	**CYCL**	**WAVE L-ET**
Robustness	Less robust than other methods	Less robust maximizes SNR	Robust to noise and perform better in low SNR	More robust than others
Accuracy	Less accurate than rest other methods	Accurate, but less than waveform	Better accurate than ED	More accurate than others
Complexity	Less complex	More complex	More complex	Less complex than MF and Cyclo
Requirement	No	SU's has priori	It also require	No priori

of PU's information		information of PU's	priori information	information is required

3.4.3 Analysis of Cooperative Spectrum Sensing Model

Cooperative spectrum sensing is a method in, which multiple cognitive radios collaborate or cooperate to each other either by sending their decisions statistics to a common node and the final decision is made by the base station. This sensing is more powerful than others because it can overcome the hidden terminal problem, which occurs when a PU's is shadowed by an obstacle, so that the cognitive user or SU's can't detect it, resultant of this cause high interference with PU's. The major challenges of cooperative spectrum sensing are applying best optimization and increased complexity. The Centralized Coordinated, decentralized coordinated and decentralized uncoordinated cooperative sensing techniques were analyzed

A) Centralized Sensing

In centralized cooperative sensing, a central unit is present which collect all sensing information from cognitive devices or secondary user and identifies available spectrum, then broadcast this sensing information to other secondary user without causing any interference. This central unit or fusion Centre makes a global decision that the PU is present in the channel. The crucial task of the centralized sensing is to mitigate the fading effects of the various channels and increase detection performance.

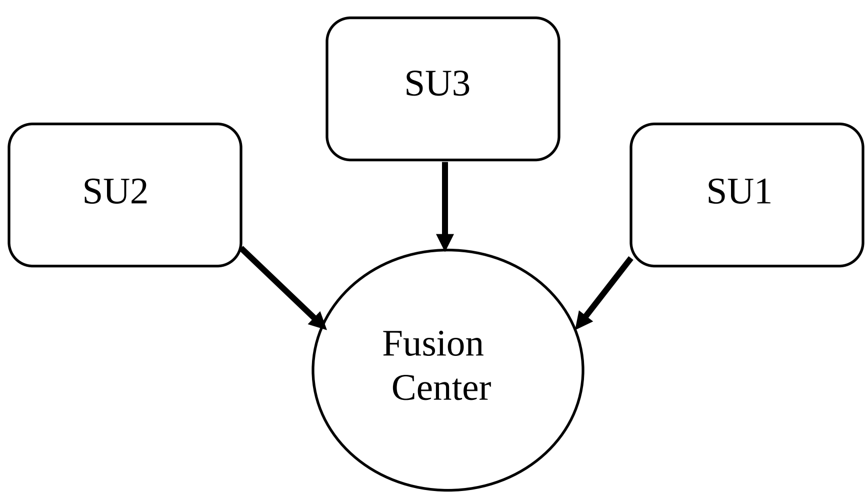


Figure 3.5: Centralized Cooperative Sensing

B) Decentralized Coordinated Sensing

Distributed sensing has one more advantage over centralized sensing, there is no need for a backbone infrastructure and it reduced cost. Collaboration is performed between two or more cognitive user. The main concept of distributed sensing is secondary user share their sensing information among themselves. Only final decision is shared in order to minimize the network overhead due to collaboration. Though, this method can improve the sensing performance as well as detection capability of system. However, the cooperative sensing techniques are faced with the following challenges:

The CR users need to perform sensing at periodic intervals as sensed information become obsolete fast due to factors like mobility, channel impairments etc. This considerably increases the data overhead;

Wide channel has to be scanned; only a portion of it changes at a time requiring updating only the changed information and not all the details of the entire scanned spectrum.

C) Interference Based Detection Model

Interference based detection was also analyzed and it has the following.

Primary Receiver Detection: Primary receiver emits the local oscillator (LO) leakage power from its Radio Frequency (RF) front end while receiving the data from primary transmitter. This method though suggested as a method to detect primary user by mounting a low cost sensor node close to a primary user's receiver in order to detect the local oscillator (LO) leakage power emitted by the

RF front end of the primary user's receiver which are within the communication range of CR system users. The local sensor then reports the sensed information to the CR users so that they can identify the spectrum occupancy status. However, this method cannot be used to identify optimal spectrum opportunities for CR users in spectrum overlay.

Interference Temperature Management: Unlike the primary receiver detection, the basic idea behind the interference temperature management is to set up an upper interference limit for given frequency band in specific geographic location such that the CR users are not allowed to cause harmful interference while using the specific band in specific area. Typically, CR user transmitters control their interference by regulating their transmission power (their out of band emissions) based on their locations with \respect to primary users. This method basically concentrates on measuring interference at the receiver. Basically, in a heavy traffic situation interference minimization cannot be guaranteed using this method.

Challenges with the Analyzed Spectrum Sensing Model

Channel Uncertainty: Because of fading or shading of the channel there will be uncertainties in the received signal strength which will lead to wrong interpretation. To avoid this Cognitive Radios must have high sensitivity so that it can differentiate between faded primary signal and a white space. If the fading is severe, a single cognitive radio cannot give high sensitivity to handle this, therefore it is better to go for a set of cognitive radios which share their local measurements and collectively decide on the occupancy state of a licensed band.

Noise Uncertainty: The detection sensitivity can be defined as the minimum Signal-to-Noise-Ratio (SNR) at which the primary signal can be accurately detected by the cognitive radio and is given by

$$\gamma_{min} = \frac{PpL(D+R)}{} \qquad 3.15$$

N

Where N = Noise power.

Pp = Power Transmitted by Primary User.

D = Interference Range of Secondary User.

R = Maximum distance between Primary Transmitter and corresponding Receiver.

The noise power estimation is limited by calibration errors as well as changes in thermal noise caused by temperature variations. Since a cognitive radio may not satisfy the sensitivity requirement due to underestimate of N, ɤmin should be calculated with the worst case noise assumption, thereby necessitating more sensitive detector.

Sensing Interference Limit: There are two factors for this issue that is when an unlicensed user may not know exactly the location of the licensed receiver which is required to compute interference caused due to its transmission and the second reason is that if a licensed receiver is a passive device, the transmitter may not be aware of the receiver. So these factors need attention while calculating the sensing interference limit.

3.4.4 Analysis of the Existing Optimization Model

Various modern heuristic algorithms have been developed for solving numeric optimization problems. These algorithms can be divided into different groups depending on the criteria being considered, such as population based, iterative based, stochastic, etc. There are mainly two groups of population based algorithms: evolutionary algorithms (EA) and swarm intelligence based algorithms.

Genetic Algorithm

Analysis of different optimization models shows that the most reliable among evolutionary algorithm is the genetic algorithm which has the ability to adapt to the radio environment. Among the artificial intelligence techniques proposed in the research field of cognitive radio networks, there are expert systems, artificial neural networks, fuzzy logic, hidden markov model and genetic algorithm. These entire decision algorithms adopt different types of reasoning to achieve an optimal solution. But each algorithm has severe limitations that reduced their operational value in real time in cognitive radio network. Fuzzy logic allow approximate solutions to be found in uncertain inputs which do not permits proving that the system has an optimal behavior. Neural networks are most applicable in this field but their computational complexity is higher than other methods. Genetic algorithm is more popular for their rapidity to cover a large space of possible configuration, and thus find the most suitable solution. The genetic algorithm is a method for solving both constrained and unconstrained optimization problems, basically which is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly renovates a population of individual solutions. Genetic algorithm can be applied to solve a several optimization problems that are not well suited for standard optimization algorithms, including various problems in which the objective function is discontinuous, non-differentiable, or highly nonlinear.

The genetic algorithms (G.A.) are typically characterized by the following aspects:

- The G.A. work with the base in the code of the variables group (artificial genetic strings) and not with the variables in themselves.
- The G.A. work with a set of potential solutions (population) instead of trying to improve a single solution.
- The G.A. do not use information obtained directly from the object function, of its derivatives, or of any other auxiliary knowledge of the same one.
- The G.A. applies probabilistic transition rules, not deterministic rules.

The genetic algorithm process is quite simple; it only involves a copy string, partial string exchanges or a string mutation, all these in random form.

The fundamental theorem of genetic algorithms

A genetic algorithm is constructed by stochastic operators, and its robust search ability is based on the under laying theorem, which includes, short schemata of low order with aptitude above average, exponentially increase its number by generations, this is:

$$m(H,t+1) \geq m(H,t)\frac{f(H)}{f_{avg}}\left[1 - p_c\frac{\delta(H)}{l-1} - O(H)p_m\right] \quad 3.16$$

where

m*(H,t+1)* and ***m****(H,t)* are the schemata number *H* in the generation *t+1* and *t* respectively, ***f****(H)* is the average aptitude value of the strings that is included on the schemata *H*, f_{avg} is the total population's average aptitude value, *l* is the total string length, δ*(H)* is the schemata length from *H*, ***O****(H)* is the schemata order from *H*, P_c is the crossover probability and P_m is the mutation probability.

Genetic Algorithm Operators

A basic genetic algorithm that can produce acceptable results in many practical problems is composed of three operators:

- Reproduction
- Crossover
- Mutation

The reproduction process goal is to allow the genetic information, stored in the good fitness artificial strings, survive the next generation. The typical case is where the population's string has assigned a value according to its aptitude in the object function. This value has the probability of being chosen as the parent in the reproduction process of a new generation.

The crossover is a process by which a string is divided into segments, which are exchanged with the segments corresponding to another string. With these processes two new strings different to those that produced them are generated. It is necessary to clarify that the choice of strings crossed inside those that were chosen previously in the reproduction process is random. From the point of view of problem optimization, it is equal to the exploitation of an area of the parameters space.

If a design variable requires a precision A_c then the number of binary digits in the binary string can be estimated with the following equation:

$$2^m \geq \frac{X_U - X_L}{A_C + 1} \quad 3.17$$

where X_U and X_L are the upper and lower bounds of the continuous variable X. It is advisable to adapt the precision to the problem, because the search process can be faulty when more precision by a longer string is required.

Selection Strategies

At first the genetic algorithms generate random strings for the solution population. The following generation is developed by applying the genetic operators: reproduction, crossover and mutation. The new generation is evolved based on each individual's probabilities assigned by its object function fitness; i.e., for poor object function fitness values there are few probabilities for surviving the next generation. In this way, the generations are engendered with the strings or individuals that improve the function objective fitness value. Those that do not cover these conditions disappear completely.

The reproduction is in essence a selection process. The good known selection outlines are: the proportional schema, or group one. The process of proportional selection assigns a reproduction range according to the fitness value to each individual. In the group selection process, the population is divided into groups according to their fitness value; where each group member will have the same reproduction value. For instance, the proportional selection could be expressed mathematically in the following way:.

$$P_i = \frac{f_i}{\sum f_j} \qquad 3.18$$

where P_i is the selection probability, f_i is the aptitude of the *i-th* individual or string and Σf_i is the sum of the population's fitness. Another form is to use the reciprocal of the object function to obtain the gross fitness *f*, i.e.:

$$f = \frac{1}{FO} \qquad 3.19$$

where *FO* is the object function value for the *i-th* string.

The optimizations in electromagnetic problems often involve many parameters in which the parameters may be discrete. For instance, a low side-lobes optimization of elements non-equidistantly spaced on a long array antenna, when the excitation and phase have quantized values.

The radiation pattern generated by an array antenna, is given by:

$$AF(\phi) = 2\sin\phi \sum_{n=1}^{N_{el}} \cos\left[k\left(\sum_{m=1}^{n} d_m - d_l/2\right)\cos\phi\right] \qquad 3.20$$

where $d_l/2$ is the distance from the element *l* to the physical center of the array, d_m is the space between the element *m-1* and element *m*. The distance of the element *m* to the center of the array is given by:

$$\left(\sum\nolimits_{m=1}^{n-1} d_m - d_l/2\right) \qquad 3.21$$

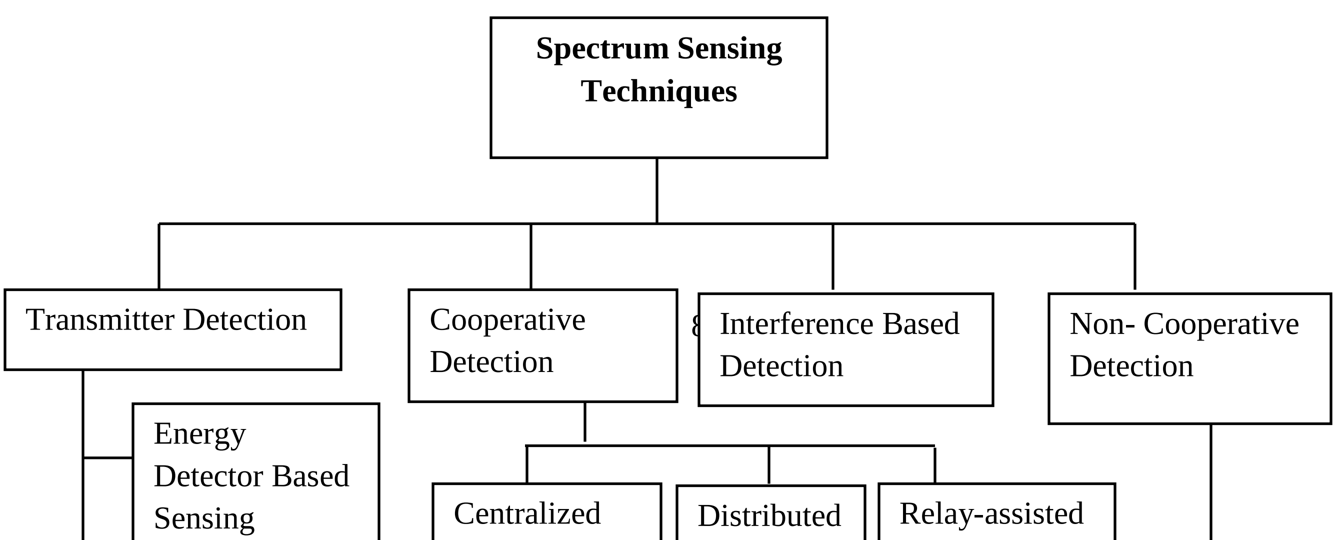
which assures element *n* is nearest to the array center than element *n+1*, and also that the minimum distance bigger than zero is considered. It is clear that the problem gets complicated when the number of array elements is increased.

Another case is the prediction of far field from near field measurements, the mathematical pattern used in the prediction of far field involves great parameter quantity, such as complex excitation, position and orientation of the physical set of the elemental dipoles that generate the same pattern to the one obtained with measurements. In this optimization problem the parameters quantity grows in proportion with the number of elements considered (8 parameters by element). For instance, if a set of four elemental dipoles is used to predict the far field of some electronic device, the search space will have 28 parameters and each one of these in an interval. For this particular case the object function proposed is:

$$F(s) = \sum_{m=1}^{M} g_m \left(v_m - f_m \left(r_m, s \right) \right) = 0 \quad 3.22$$

where v_m is the measured real value, $f_m(r_m,S)$ is any amplitude or phase (calculated with the field expressions for elementary dipoles of any electric or magnetic field component vector radiated by the group of equivalent dipoles, both values in the point r_m); g_m is a weight function which depends on the information kind (excitation and/or phase); S is a vector formed by the excitation, position and orientation dipole parameters. A way of finding S is by minimizing $|F|$. Since $|F|$ is highly non-linear and it has too many local minima, it is only probable to find a global optimal with non-conventional optimization methods, such as the genetic algorithms.

The sensing techniques of the existing system is summarized in figure 3.6



3.4.5 Architecture of Existing System

CR networks can be divided in two groups, the primary network and the cognitive network. The primary network is a licensed network that has exclusive right to access a specific frequency band. Cognitive networks do not have a license to operate in the desired band, and is often referred to as the secondary network. The fundamental components and architecture of a CR network, as defined by Rondeau (2008) and represented in figure 3.7 are as follows:

Primary User: A primary user has a license to operate in a certain spectrum band. Its access can be only controlled by the base-station and should not be affected by other unauthorized users.

Primary Base-Station: Primary base-station is a fixed infrastructure network component with a spectrum license. Sometimes, primary base-station may require both licensed and CR protocols for the primary network access of CR users.

Cognitive Radio User: Is an unlicensed user, so the spectrum access is allowed only opportunistically. The CR user should have the capabilities of spectrum sensing, spectrum decision and spectrum mobility. It has to be able to communicate with other CR users apart from the base-station.

Cognitive Radio Base-Station: CR base-station is a fixed infrastructure component with CR capabilities. It provides single hop connection to CR users without spectrum access license.

As mentioned, CR users can communicate both with the base-station and other CR users. In consequence, there are three possible access types in a CR network.

Cognitive Radio Network Access: This access occurs when a CR user accesses its own CR base station. All the operations take place inside the CR network so their medium access scheme is independent of the primary networks.

Cognitive Radio Ad Hoc Access: This access occurs when a CR user communicates with other CR users through Ad Hoc connection. CR users can have their own medium access technology.

Primary Network Access: This access occurs when a CR user accesses the primary base-station through the licensed band. In this case, CR users should support the medium access technology of primary network and the primary base-station should support CR capabilities.

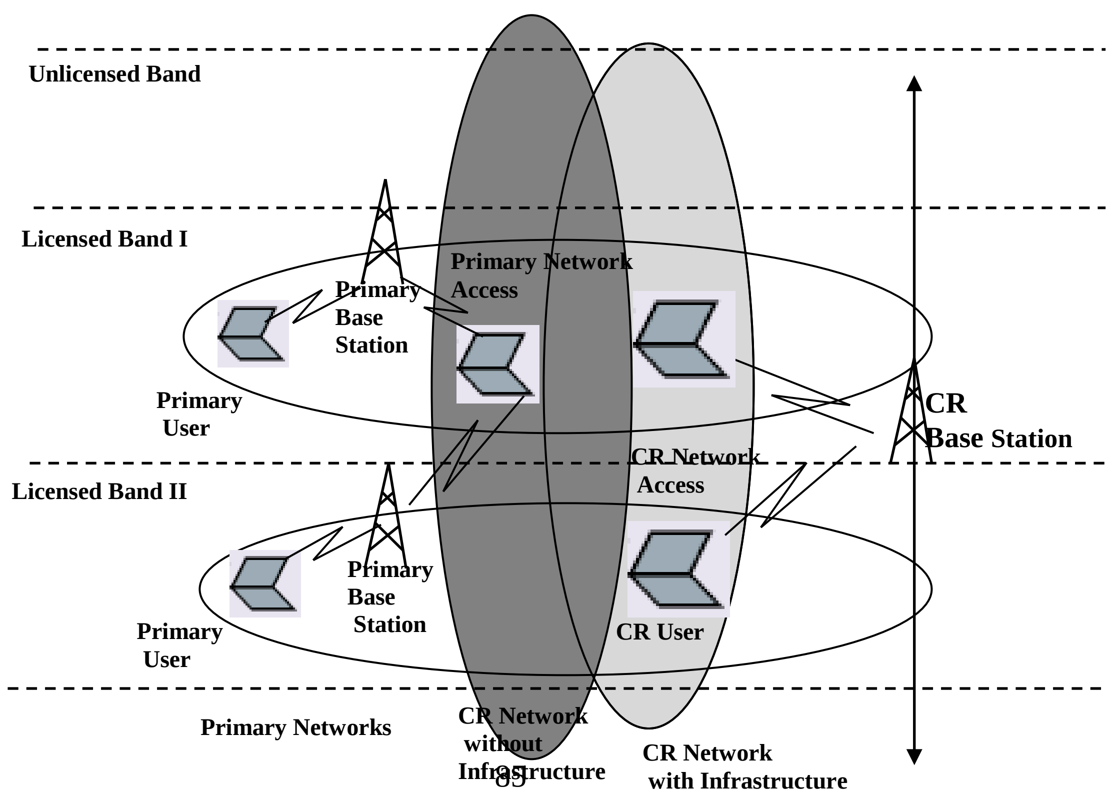


Figure 3.7: Modified Architecture for Cognitive Radio Networks
(**Source:** Rondeau, 2008)

3.4.6 Existing System Process

The basic process followed by a cognitive radio is that it adjusts its knobs to achieve some desired (optimum) combination of meter readings. Rather than randomly trying all possible combinations of knob settings and observing what happens, it makes intelligent decisions about which settings to try and observes the results of these trials. Based on what it has learnt from experience and on its own internal models of channel behavior, it analyzes possible knob settings, predicts some optimum combination for trial, conducts trial, observes the results, and compares the observed results with its predictions, as summarized in the adaptation loop of figure 3.8. If results match predictions, the radio understands the situation correctly. If results do not match predictions, the radio learns from its experience and tries something else.

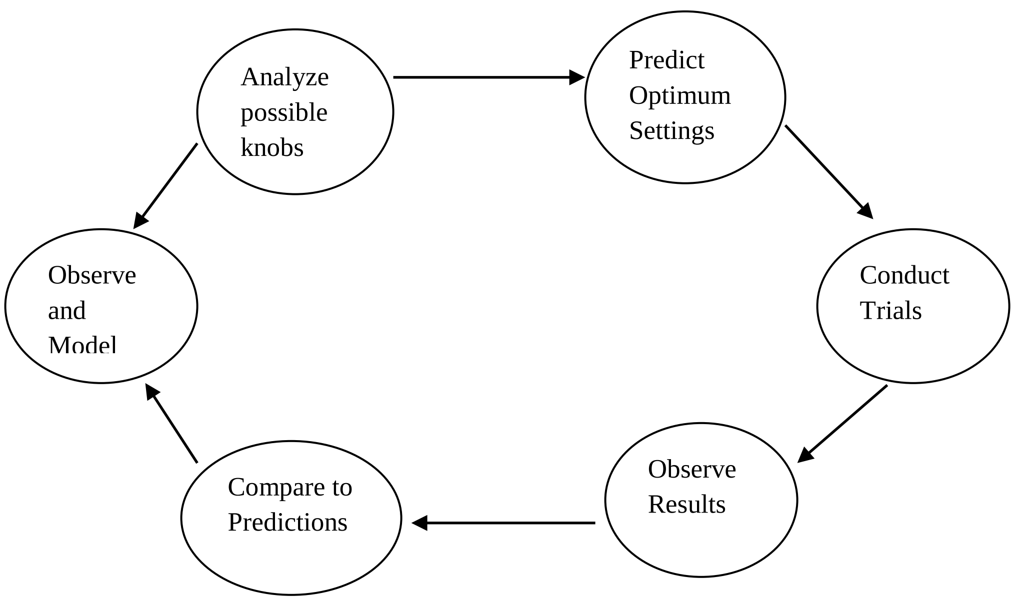


Figure 3.8: Cognitive Radio Adaptation Loop

Source: Rondeau & Bostian (2010)

This operational concept employed for the cognitive radio resembles closely some of the current thinking about how human brain works. The argument holds that human intelligence is derived from predictive abilities of future actions based on the currently observed environment. In order words, the brain first models the current situation as perceived from the sensor inputs, and it then makes a prediction of the next possible states that it should observe. When the predictions do not match reality, the brain does further processing to learn the deviation and incorporate it with its future modeling techniques. Although knowledge of how the human brain actually works is still uncertain, this predictive model is a good one to work from because it brings the necessary behavior required from cognitive radio. However, in cognitive radio networks, there are two types of users: licensed or primary users (PUs), and unlicensed or secondary users (SUs). PUs can access the wireless network resources according to their license while SUs are equipped with cognitive radio capabilities to opportunistically access the spectrum. Cognitive radio capability allows SUs to temporarily access the PUs' under-utilized licensed channels. To improve spectrum usage efficiency, cognitive radio must combine with intelligent management methods. In the following subsection, we first describe CR primary functions and then, we detail proposed solutions to improve dynamic spectrum access.

3.4.7 Disadvantages of the Existing System

The existing system has the following disadvantages:

i) In the existing system, the signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor, or it can be said that the decision threshold is subject to changing signal-to-noise ratios.
ii) It has the difficulty of distinguishing primary signals from the CR user signals and it is faced with high computational complexity

iii) It does not work efficiently for detecting spread spectrum signals and it takes high sensing time to achieve a given probability.

iv) Cognitive radio users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing.

v) The energy threshold used for detection by the existing system is highly susceptible to unknown or varying noise power levels and threshold values need to be adjusted adaptively.

vi) Under frequency selective fading, deciding energy threshold value is difficult with channel notches and sophisticated mechanism has to be employed.

vii) It requires more complicated signal processing algorithms in order to work with spread spectrum signals like direct sequence and frequency hopping.

viii) The existing system cannot differentiate between modulated signals, noise and interference and hence, therefore, cannot benefit from interference cancellation techniques.

ix) It is faced with poor performance under low Signal-to-Noise ratio (SNR) value and its detection performance is subject to the uncertainty of noise power.

x) The existing system requires perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format.

xi) For Matched filter detection, CR would need a dedicated receiver for every type of primary user.

xii) Since cognitive radio needs receivers for all signal types, the implementation complexity of sensing unit is practically large.

xiii) The existing system is characterized by large power consumption as various receiver algorithms need to be executed for detection.

xiv) Analyzing matched filter, it is apparent that this method is only applicable to systems with known signal patterns, such as wireless metropolitan area network (WMAN) signals, thus this method is often referred to as a waveform-based type of sensing. The existing system works on the signals characteristics.

xv) Though the number of features generated in the signal is increased in order to increase the robustness against multipath fading, however, this comes at the expense of increased overhead and bandwidth loss.

xvi) Channel effects such as Doppler shift and/or fading diminish the periodic nature of the signal phase-transitions (e.g., modulation), and thus can also reduce the practical extent of data collection.

xvii) The cognitive radio users need to perform sensing at periodic intervals as sensed information become obsolete due to factors like mobility, channel impairments etc. This considerably increases the data overhead

xviii) Another challenge of existing system includes developing efficient information sharing algorithms and increased complexity.

3.5 Analysis of the New System

The recent growth in size and complexity of communication systems and consumer’s expectations of being always connected anywhere and anytime has necessitated the need to improve on the current technologies. The introduction of smartphones, the popularity of social networks, growing media sites such as Youtube, Hulu, flickr, introduction of new devices such as e-readers, have all added to the already high and growing use of cellular networks for conventional data services such as email and web-browsing. It has become clear that the assumption of controlling and monitoring the systems through a central entity is no longer valid. Traditionally, network analysis, diagnosis and management have been done manually by a number of people. As the Internet continues to grow in reach and in density, we have seen increasing problems in understanding how it works, where it runs into problems and how to address those problems. With the increased scale, penetration, and distribution of the Internet, those traditional manual approaches require an increasing number of people to be involved, and the management task itself becomes increasingly complex. Therefore, a central problem is to make the network self-knowledgeable, self-diagnosing, and perhaps in the future self-managing with very little human intervention.

The system we intend to build is a simulation of Optimized TV White Space Sensing and Allocation to Secondary Users (TVWSOUGA) using Genetic Algorithm (GA). We shall employ the Object Oriented Analysis and Design Methodology in the analysis of the new system.

The analysis of the new system (Optimization of TV White Space Sensing and Allocation) will focus mainly on identification of operational (analysis) objects in the new system, analyzing the various components of the simulator with the view of formulating a High Level Model (HLM) diagram of the new system.

Genetic Algorithm (GA) has been adopted for the optimization of the sensing and allocation of Spectrum to secondary users.

The new system is based on the empirical fact that the utilization of the spectrum is a function of time and location as represented in equation 3.23. This was proven by the field work carried out in different locations as seen in table 3.2.

$$\alpha = f(t, l) \qquad 3.23$$

Where α is the utilization of spectrum in percentage, t is the time and l is the location.

Hence, for different times and locations, the value of α is different as seen in the analysis below.

However, to further buttress the importance of the proposed system, some spectrum occupancy in Delta State and Anambra State with the range 474 – 874MHz was analyzed to determine the effective use of white space devices on such spectra. The areas under consideration were Nkpor and Awka in anambra state, Asaba and Ubulu-Uku in Delta State. The DVBT-2 and Anritsu Ms2711A spectrum analyzer were employed for this analysis. For optimum result the frequencies were sub-divided into four categories: category 474 – 578MHz, 578 – 682MHz, 682 – 778MHz and 778 – 874MHz.

Spectrum Occupancy Analysis in Nkpor–Onitsha Area

The frequency in Nkpor-Onitsha area was analyzed the number of channels within 474 to 570MHz range was 13; Total number of occupied channels = 2; Total number of unoccupied (white space) channels = 11; it also reveals that some of the licensed channels are occupied by their owners. This shows that in this area only 15% are occupied while 85% are free to be used by white space devices. The data for the analysis is shown in Appendix II.

When the spectrum occupancy of 578 to 674MHz was analyzed in the same zone, the total number of channels here is 13; Total number of occupied channels was 2 and free channels within this range are 11. This shows that 85% of the channels are free to be used by white space devices in that zone. The data for the analysis is shown in Appendix V.

In the frequency of 682 to 770MHz in Nkpor area, it shows that total number of 12 channels was analyzed and total of 5 were occupied while a total of 7 was unoccupied. This shows that 58% of the channel can be used by white space devices while 42% are occupied. The data for the analysis can be found in Appendix V.

For frequency 778 to 874 MHz, the analysis in this range of frequency shows that a total of 12 channels were analyzed and only 2 channels were occupied and a total of 10 channels representing 83% are unoccupied that can be used for white space devices in that zone.

From the analysis made we can deduce that in frequencies 474 to 874 MHz we a total number of fifty (50) channels. The number of occupied channels is 11 representing 22% and unoccupied channels are 39 representing 78%. Therefore the total free spectrum (white space) is 39 X 8 given us 312MHz. The proposed system shall sense the availability of these spectra for possible use of white space devices in Nkpor-Onitsh zone of Anambra State.

Spectrum Occupancy Analysis in Awka Area

More so, Awka area was also taken into consideration to determine the spectrum occupancy in that area. Below are the results:

Awka and environs was analyzed the number of channels within 474 to 570MHz range was 13; Total number of occupied channels = 2; Total number of unoccupied (white space) channels = 11, This shows that in this area only 15% are occupied while 85% are free to be used by white space devices. The data for the analysis is shown in Appendix III.

When the spectrum occupancy of 578 to 674MHz was analyzed, the total number of channels here is 13; it was discovered that all channels here were free (100%) to be used by white space devices in that zone.

In the frequency of 682 to 770MHz in Awka area, it shows that total number of 12 channels was analyzed and total of 5 were occupied while a total of 7 was unoccupied. This shows that 58% of the channel can be used by white space devices while 42% are occupied.

In the frequency of 778 to 874 MHz in Awka area a total of 12 channels were analyzed and it shows that only 2 channels was occupied and a total of 10 channels representing 83% are unoccupied that can be used for white space devices in that zone.

From the analysis made in Awka and environs, we can conclude that in frequencies 474 to 874 MHz comprising a total number of fifty (50) channels. The number of occupied channels is 9 representing 18% and unoccupied channels are 41 representing 82%. Therefore the total free spectrum (white space) is 41 X 8 given us 328MHz. The proposed system shall sense the availability of these spectra for possible use of white space devices in Awka and environs of Anambra State.

Spectrum Occupancy Analysis in Delta State

Analysis of spectrum occupancy was also carried out in Delta state and we have the following results.

When the frequency range of 474 to 570MHz in Asaba and environs was analyzed the number of channels within 474 to 570MHz range was 13; Total number of occupied channels = 5; Total number of unoccupied (white space) channels = 8. This shows that in this area 38% are occupied while 62% are free to be used by white space devices in this area.

When the spectrum occupancy of 578 to 674MHz was analyzed in that same area, the total number of channels here is 13; Total number of occupied channel was 4 and free channels within this range are 9. This shows that only 69% of the channels are free to be used by white space devices in this area.

In the frequency of 682 to 770MHz in Asaba and environs, it shows that total number of 12 channels was analyzed and total of 11 out of the 12 were occupied. This shows that 92% of the channels were occupied; it also shows that white space devices may not be deployed to this frequency range in this area to avoid interference. Hence it can be termed red zone or “no go area” zone.

Also a total of 12 channels were analyzed for frequency 778 to 874 MHz and it shows that only 2 channels were occupied and a total of 10 channels representing 83% are unoccupied that can be used for white space devices in that zone.

From the analysis made we can comfortable say in frequencies 474 to 874 MHz we have a total number of fifty (50) channels. The number of occupied channels is 22 representing 44% and unoccupied channels are 28 representing 56%. Therefore the total free spectrum (white space) is 28 X 8 given us 224MHz. The proposed system shall sense the availability of these spectra for possible use of white space devices in Asaba and environs of Delta State.

Ubulu-Uku Zone in Delta State.

When the spectrum occupancy in Ubulu-Uku and environs was analyzed the number of channels within 474 to 570MHz range was 13; Total number of occupied channels = 7; Total number of unoccupied (white space) channels = 6; it also reveals that some of the licensed channels are occupied by their owners. This shows that in this area 54% are occupied while only 46% are free to be used by white space devices.

When the spectrum occupancy of 578 to 674MHz was analyzed, the total number of channels here is 13; Total number of occupied channels was 7 and free channels within this range are 6. This shows that 46% of the channels are free to be used by white space devices in that zone.

In the frequency of 682 to 770MHz in Ubulu-Uku area, it shows that total number of 12 channels was analyzed and total of 9 were occupied while a total of 3 was unoccupied. This shows that only 25% of the channel can be used by white space devices in this area while 75% are occupied.

Also for frequency 778 to 874 MHz a total of 12 channels were analyzed and it shows that only 2 channels was occupied and a total of 10 channels representing 83% are unoccupied that can be used for white space devices in this area while 17% are occupied.

From the analysis made we can comfortable say in frequencies 474 to 874 MHz we have a total number of fifty (50) channels. The number of occupied channels is 25 representing 50% and unoccupied channels are 25 representing 50%. Therefore the total free spectrum (white space) is 25 X 8 given us 200MHz. The proposed system shall sense the availability of these spectra for possible use of white space devices in Nkpor-Onitsh zone of Anambra State.

Table 3.2: Channel utilization in different location

S/N	**No of channels Analyzed**	***α* (utilized in percentage)**	***l* (location)**	***t* (time)**
1	50	22	Nkpor-Onitsha	As at the time of carrying out this field work
2	50	18	Awka & Environs	As at the time of carrying out this field work
3	50	44	Asaba & Environs	As at the time of carrying out this field work
4	50	50	Ubulu-Uku area	As at the time of carrying out this field work

Figure 3.9 shows the graphical representation of the analyzed spectrum occupancy in four area – Nkpor and environs, Awka and environs, Asaba and environs, Ubulu-Uku and environs. From the graph we have more free spectra

that can be used for white space devices in Nkpor and Awka areas of Anambra State then in Asaba and Ubulu-Uku of Delta State.

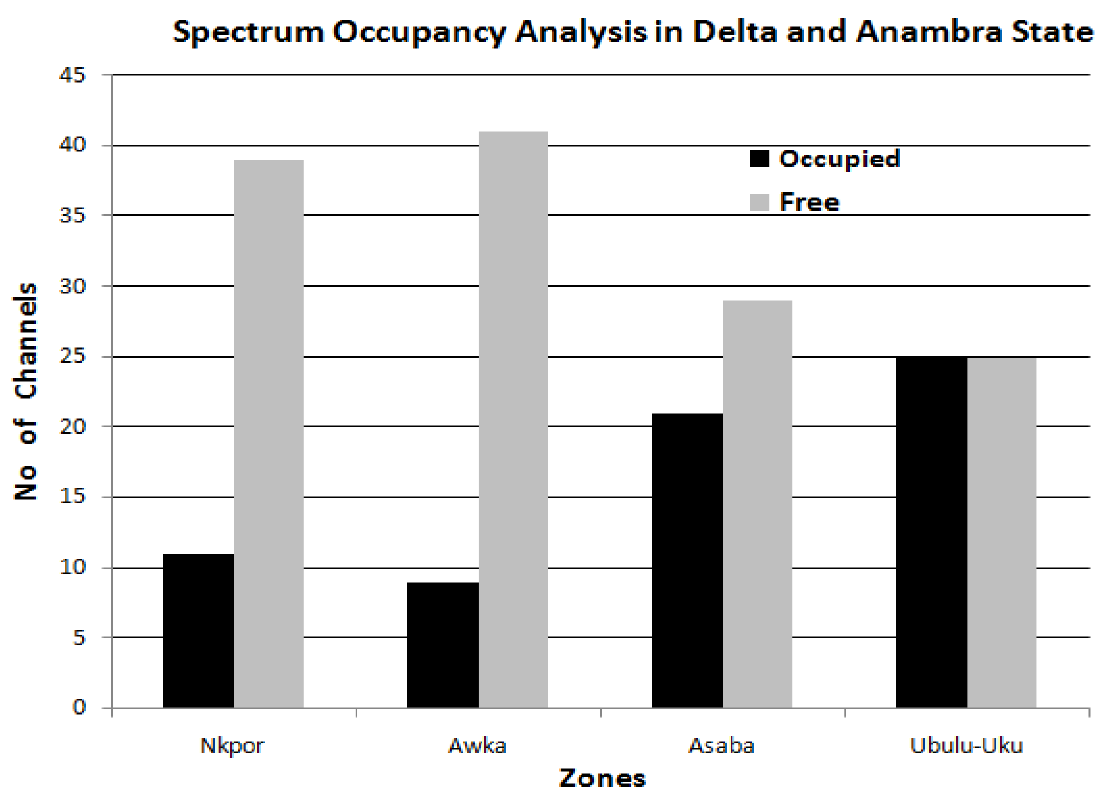


Figure 3.9: Spectrum Occupancy for four Zones

Figure 3.10: A DBVT-2 Decoder showing unoccupied channel

Figure 3.10 shows a frequency scan using DVBT-2 device, it shows that channel 21 with 474000 KHz frequency is unoccupied in that particular zone. Also figure 3.11, shows that channel 50 with frequency 706,000 KHz is occupied in that zone, the signal intensity is 72% while the signal quality is 97%.

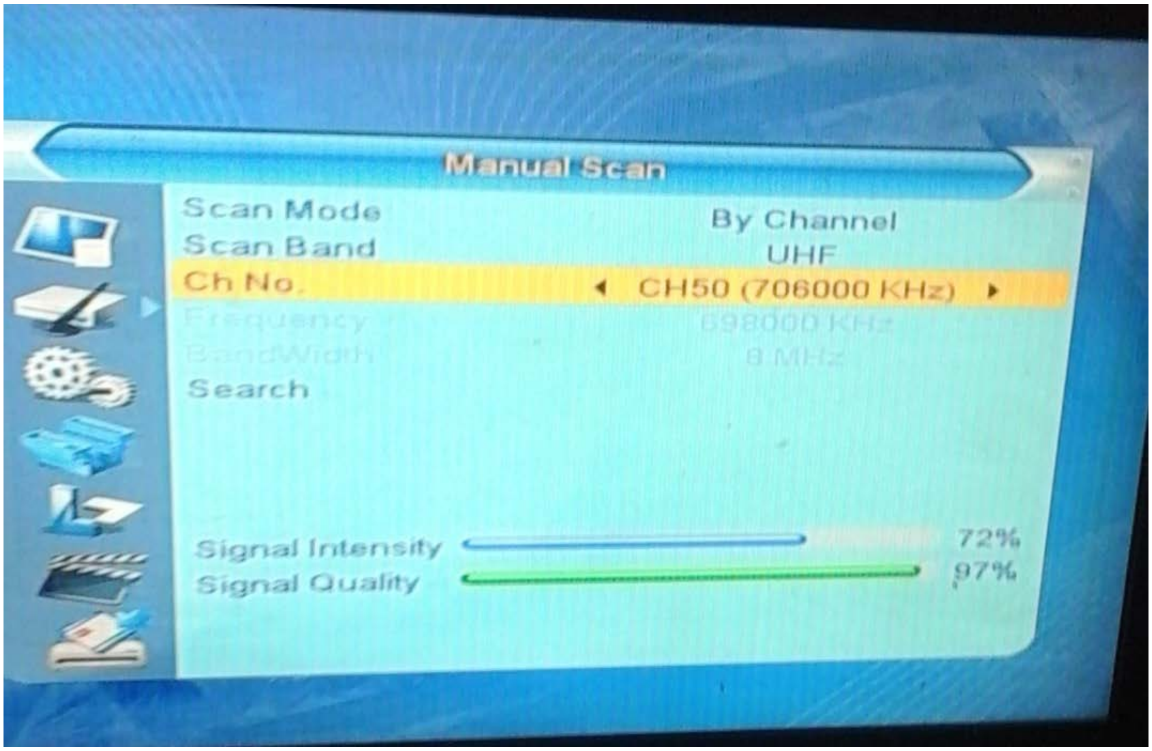
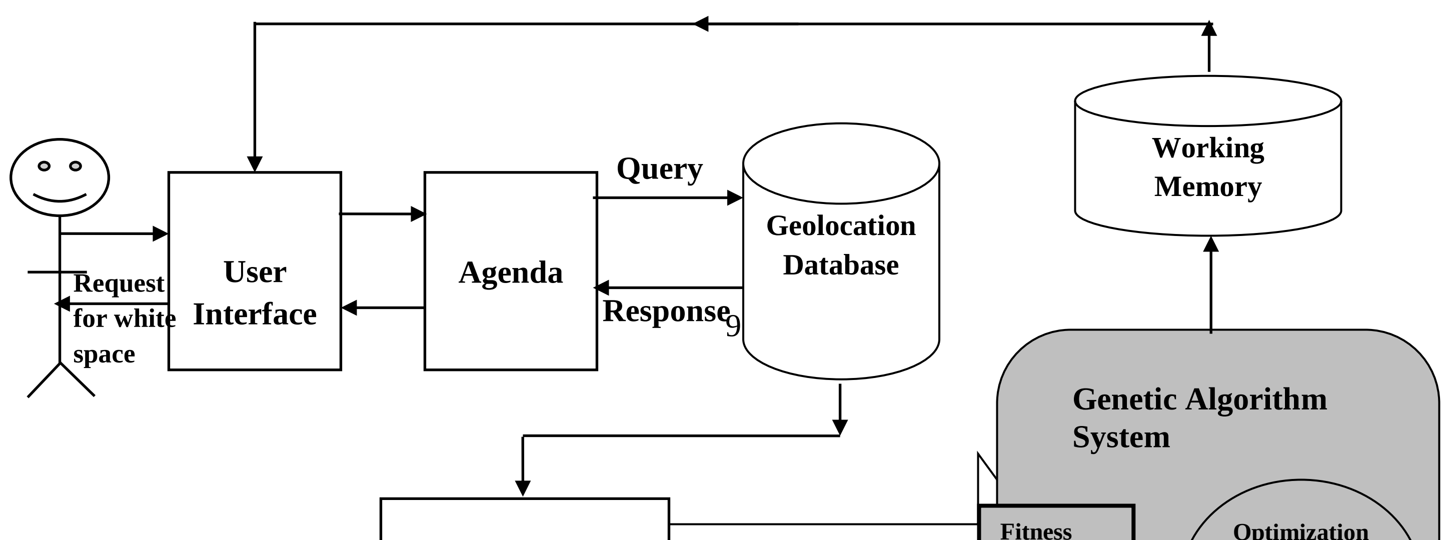


Figure 3.11: A DBVT-2 Decoder showing occupied channel

The proposed architecture for the White Space selection is being remodeled to meet the user's request as such the Genetic Algorithm (GA) is employed. Generally, in the most of real world problems, the surface of search space is not easy to identify. If the problem had many local optimum peaks, it may often trap with the premature convergence problem. Moreover, the stall generation also led to pre-mature convergence problem. To overcome some of these hitches the proposed model rule based system with GA was employed to avoid premature convergence problem.



3.5.1 Object Identification

From the foregoing analysis of the old system, the following objects were identified and formulated for the proposed system:

Table 3.3: Object description/ Responsibility

S/N	OBJECT	DESCRIPTION & RESPONSIBILITY
1.	TV White Space	TV channels freed up when a state transitions from Analog TV (ATV) to Digital TV (DTV)
2.	TVBD	TV Band Device is a low power transmitter that operates in an unoccupied TV channel in the range of channels 2-51, excluding channels 3-4 and 37
3.	TV Bands Database	This is a service that TVBDs must contact to submit their operational location and obtain TV channels availability.
4.	Rule	A relationship between clauses and depending on the situation can be used to generate new information or prove the truth of an assertion
5.	Knowledge Base	A set of if-then rules and known facts

S/N	OBJECT	DESCRIPTION & RESPONSIBILITY
6.	Clause	Assertions or facts
7.	Inference Engine	A collection of reasoning logic used to process the rules and data.
8.	Scanner	A custom made object with the capability of sensing free and unoccupied channels and assigning same to secondary users.
9.	Cognitive Radio	an intelligent wireless communication system that is aware of its surrounding environment
10.	Genetic Algorithm	Uses the principle of selection and mutation to select best fit individuals from a population sample in a search space
11.	Chromosome	Blueprint for an individual
12.	Population	A collection of individuals
13.	Individual	Any possible solution. In our case any possible free and unoccupied channel.
14.	Search Space	All possible solutions to the problem. In our case, all available frequency bands in a geographical location.
15.	Trait	Possible aspect of an individual
16.	Allele	Possible setting for a trait
17.	Locus	The position of a gene in a chromosome
18.	Genome	Collection of chromosomes for an individual
19.	Simulator	An object that simulates signal sensing and allocation to secondary Users.
20.	Optimizer	This object, optimizes the allocation of free unoccupied channels to devices with aid of Inference Engine and Cognitive Radio

RULE: A Rule for determining if a vehicle is a Sport_Car is typically of the form.

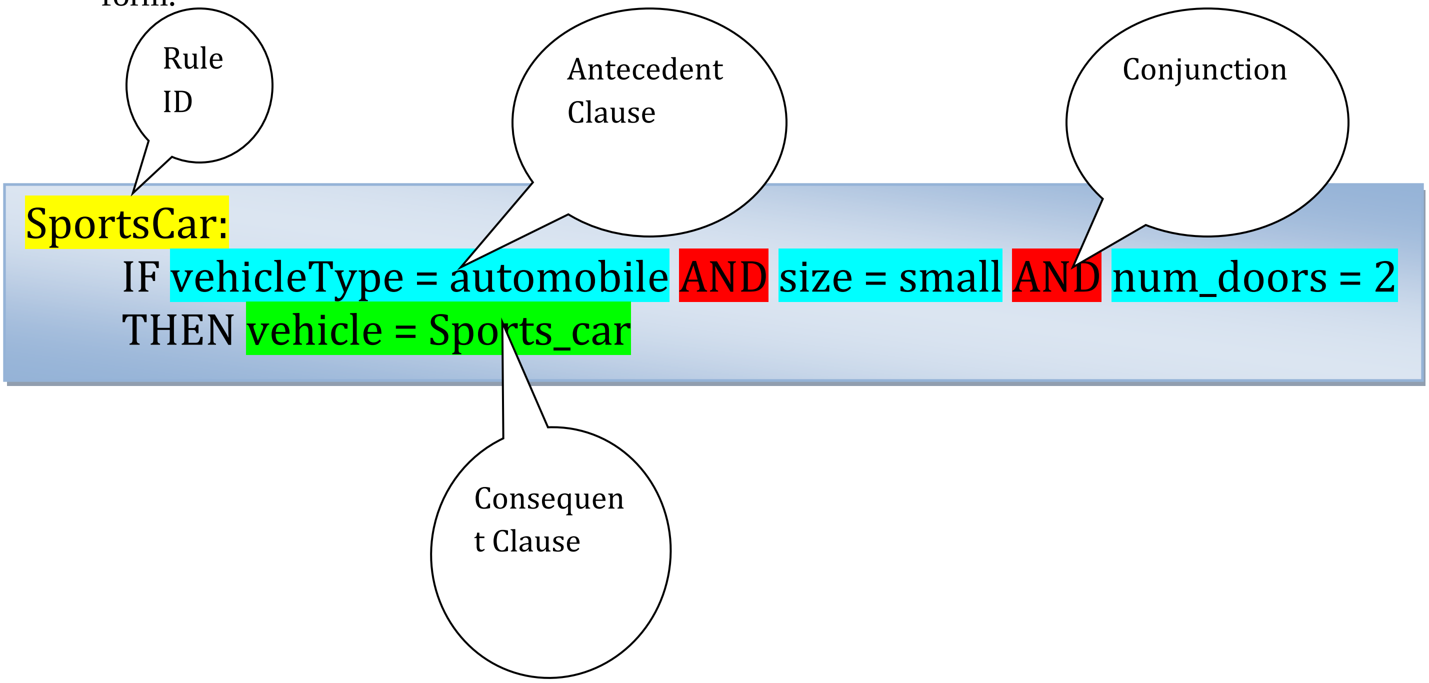


Figure 3.13: A sample Rule to determine that a vehicle is a Sports_car.

From the diagram, one can deduce that a Rule is made of:

i) An ID (Rule Id)

ii) Antecedent Clause

iii) Consequent Clause

iv) Conjunctions

Rule
<<Class>>

-ruleid: String
-antecedent: Clause[1..n]
-consequent: Clause
-conjunction: Conjunction[1..n]

+getRuleId(): String
+getAntecedent(): Clause[1..n]
+getConsequent(): Clause
+getConjunction(): Conjunction
+setRuleId(para: String)
+setAntecedent(para:Clause[1..n])
+setConsequent(): Clause
+setConjunction(para: Conjunction)

Figure 3.13 Rule Class Diagram

The Rule Class is composed of the Clause and Conjunction Class.

CLAUSE: A clause is usually made up of a Rule Variable on the Left Hand Side (LHS), a Condition which tests equality, greater than or less than, and on the Right Hand Side (RHS) a value, which in our implementation is a String (symbolic or numeric). The following diagram illustrates this concept clearly.

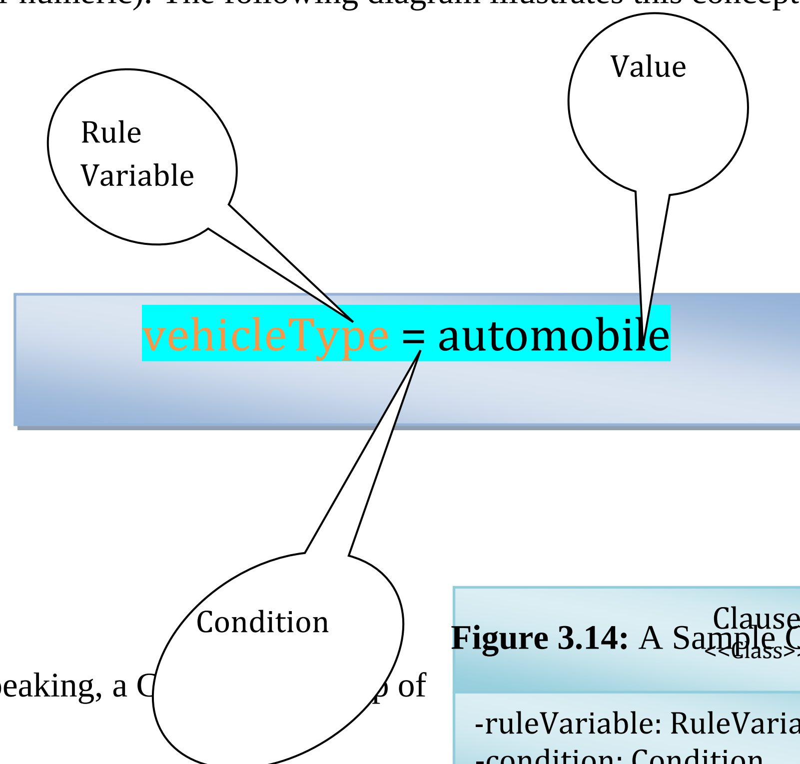


Figure 3.14: A Sample Clause

Basically speaking, a C[illegible] of

i) Rule Variable

ii) Condition

iii) Value

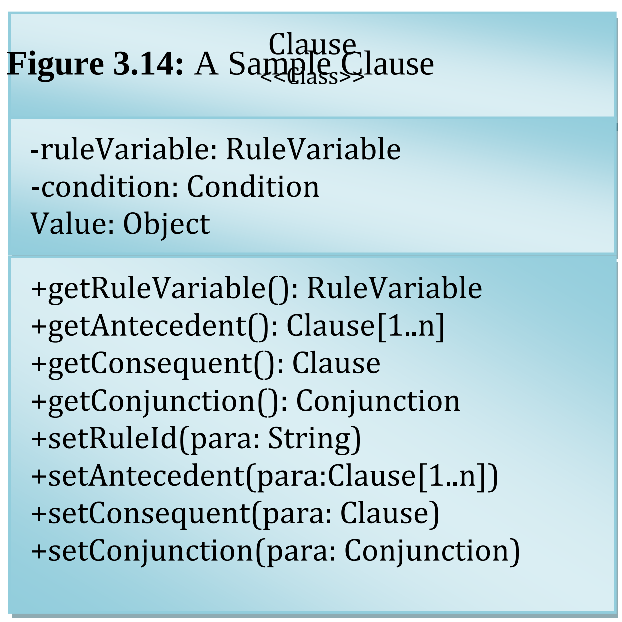


Figure 3.15: Clause Class Diagram

From the foregoing, one can easily deduce a Composition Relation between Clause and its constituents Rule Variable and Condition Classes. It is therefore safe to say that the Clause class has a Rule Variable and Condition Class.

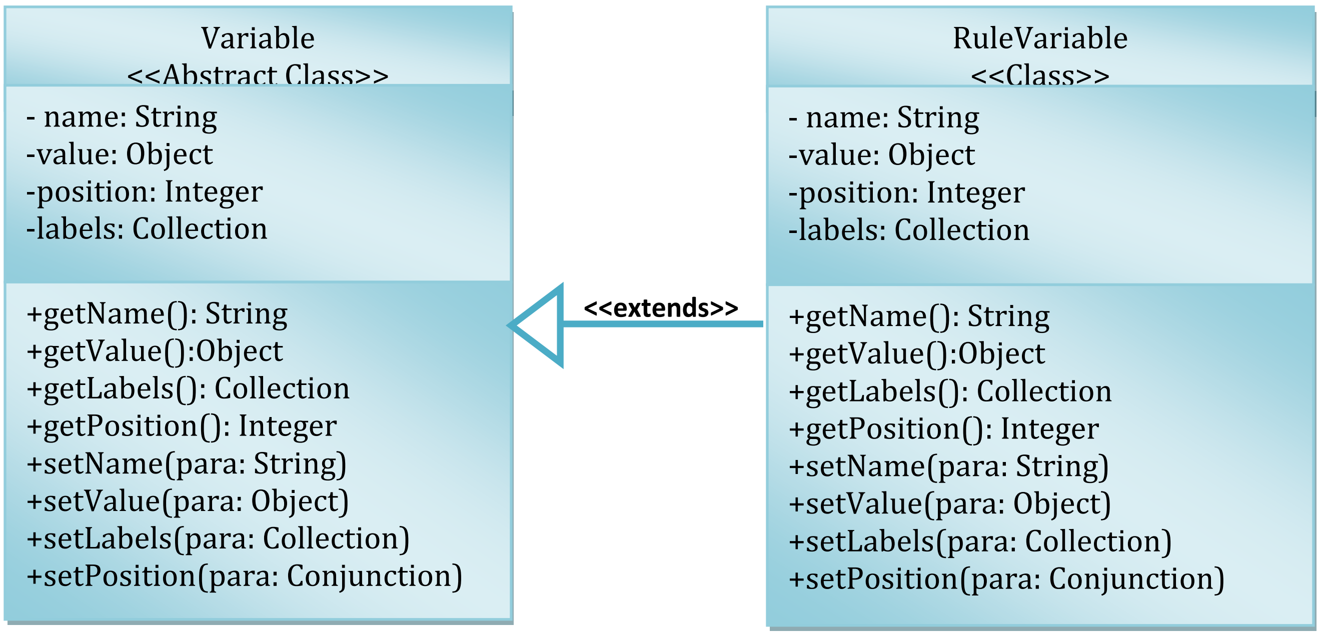


Figure 3.16: Class Diagram of RuleVariable showing Is-A (inheritance) relationship between Variable and RuleVariable classes.

The diagram above depicts a typical is-a or inheritance relationship between a supper class –i.e that is the class with attributes and method to be inherited- (Variable) and a sub class – a class that inherits the attributes and methods of another class-(RuleVariable)

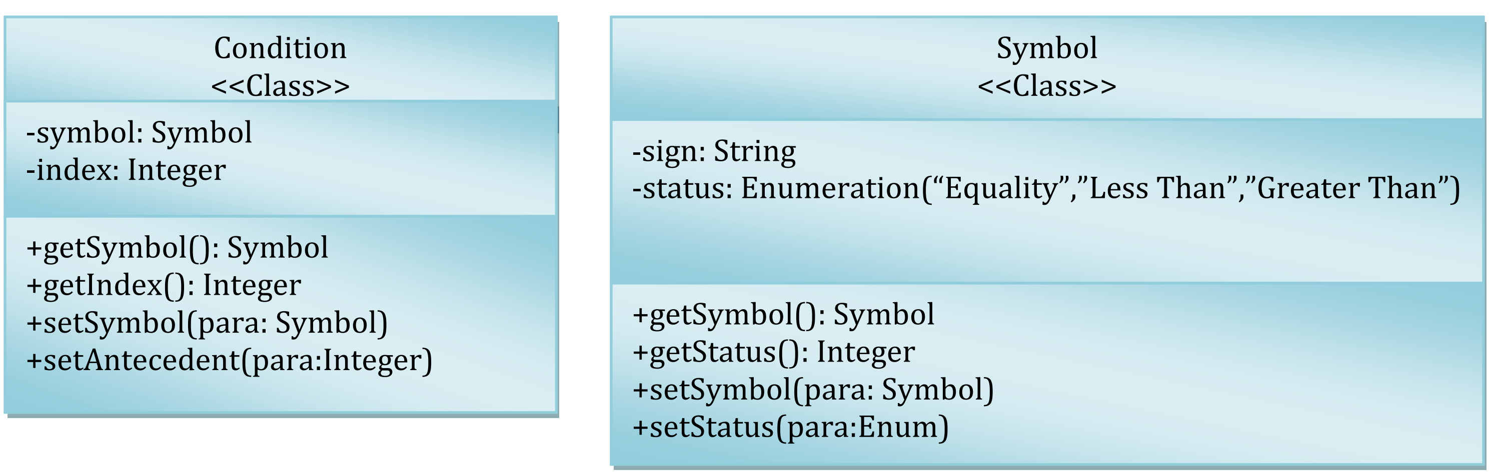


Figure 3.17: **C**lass Diagram of Condition and Symbol Class respectively

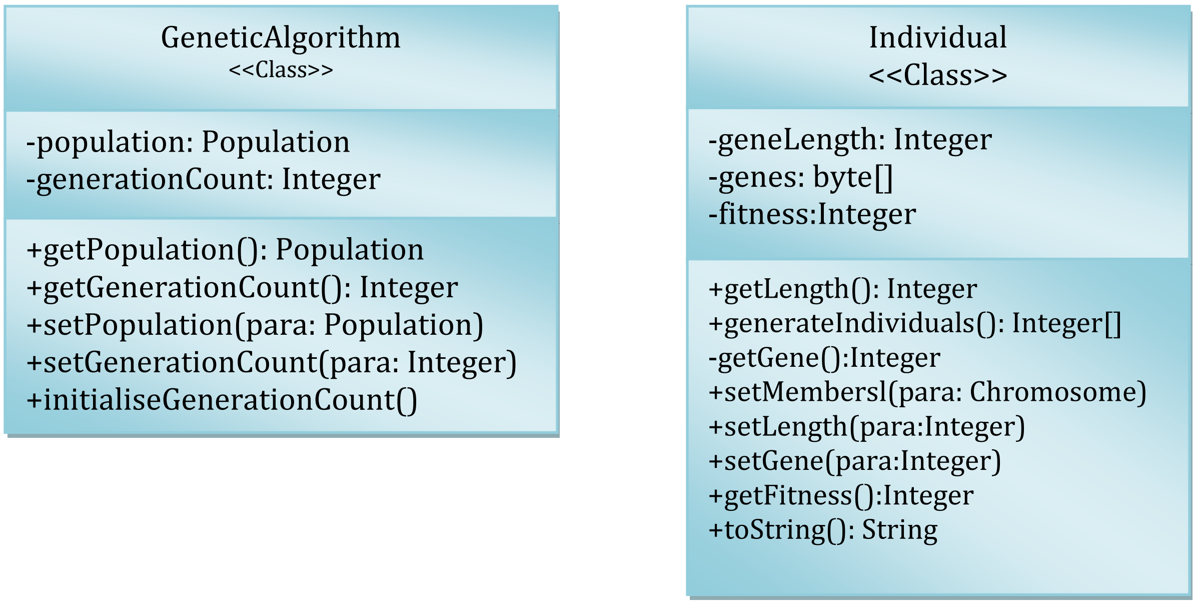


Figure 3.18: Genetic Algorithm and Individual Class Diagram

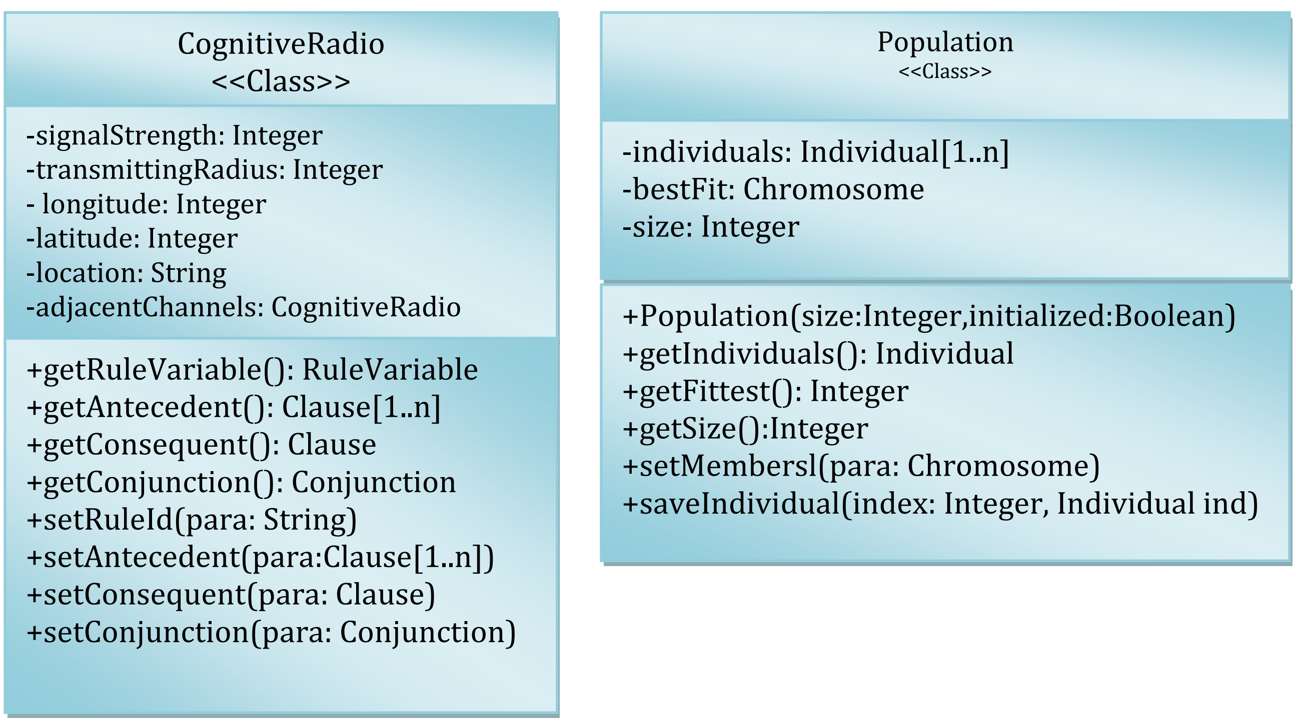


Figure 3.19: Cognitive Radio and Population Class Diagrams

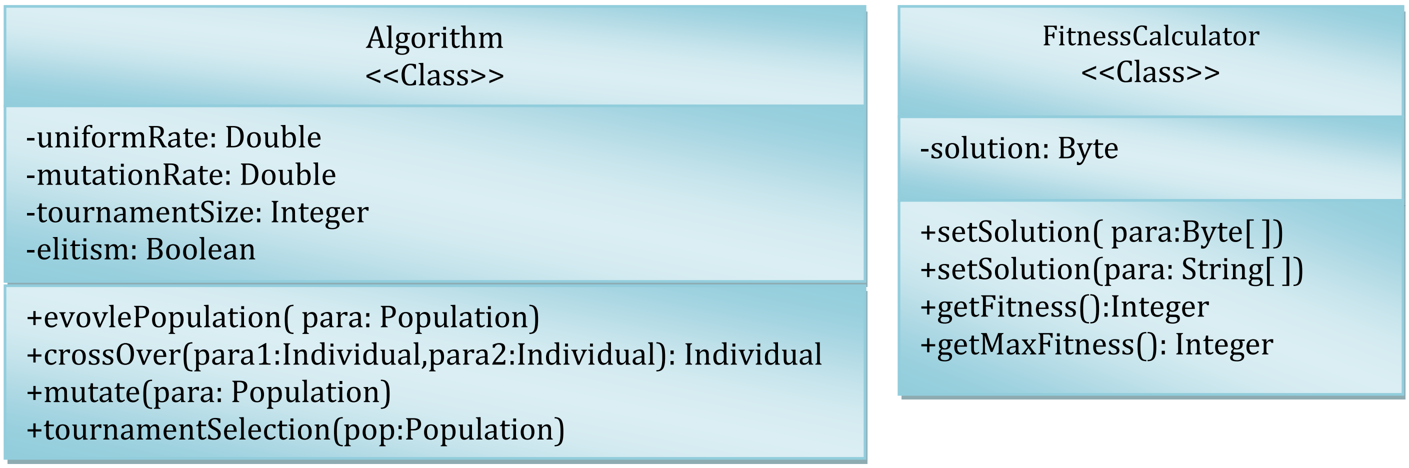


Figure 3.20: Algorithm and Fitness Calculator Class Diagrams

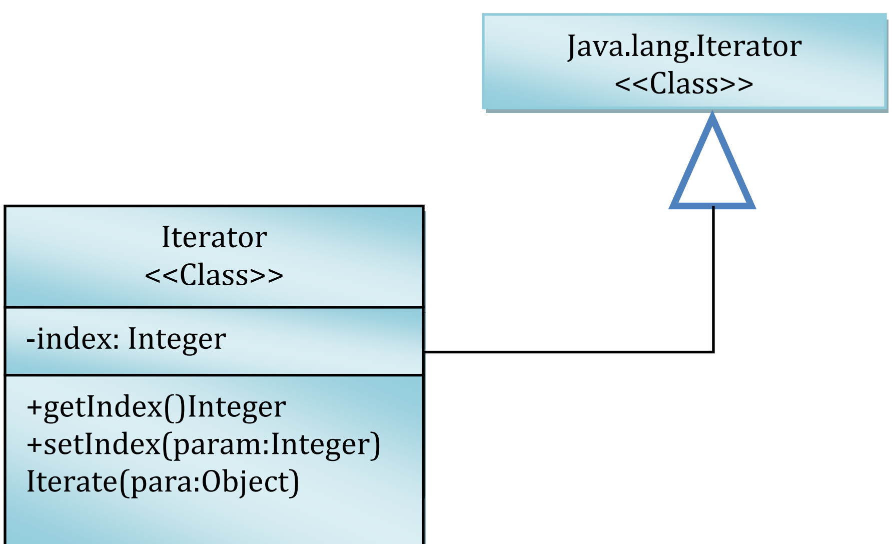


Figure 3.21: Iterator Class Diagram

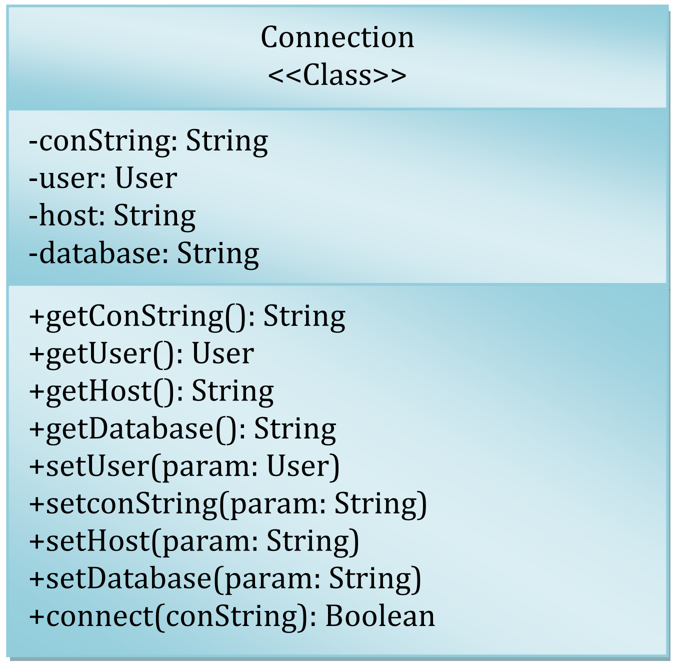


Figure 3.22: Connection Class Diagram

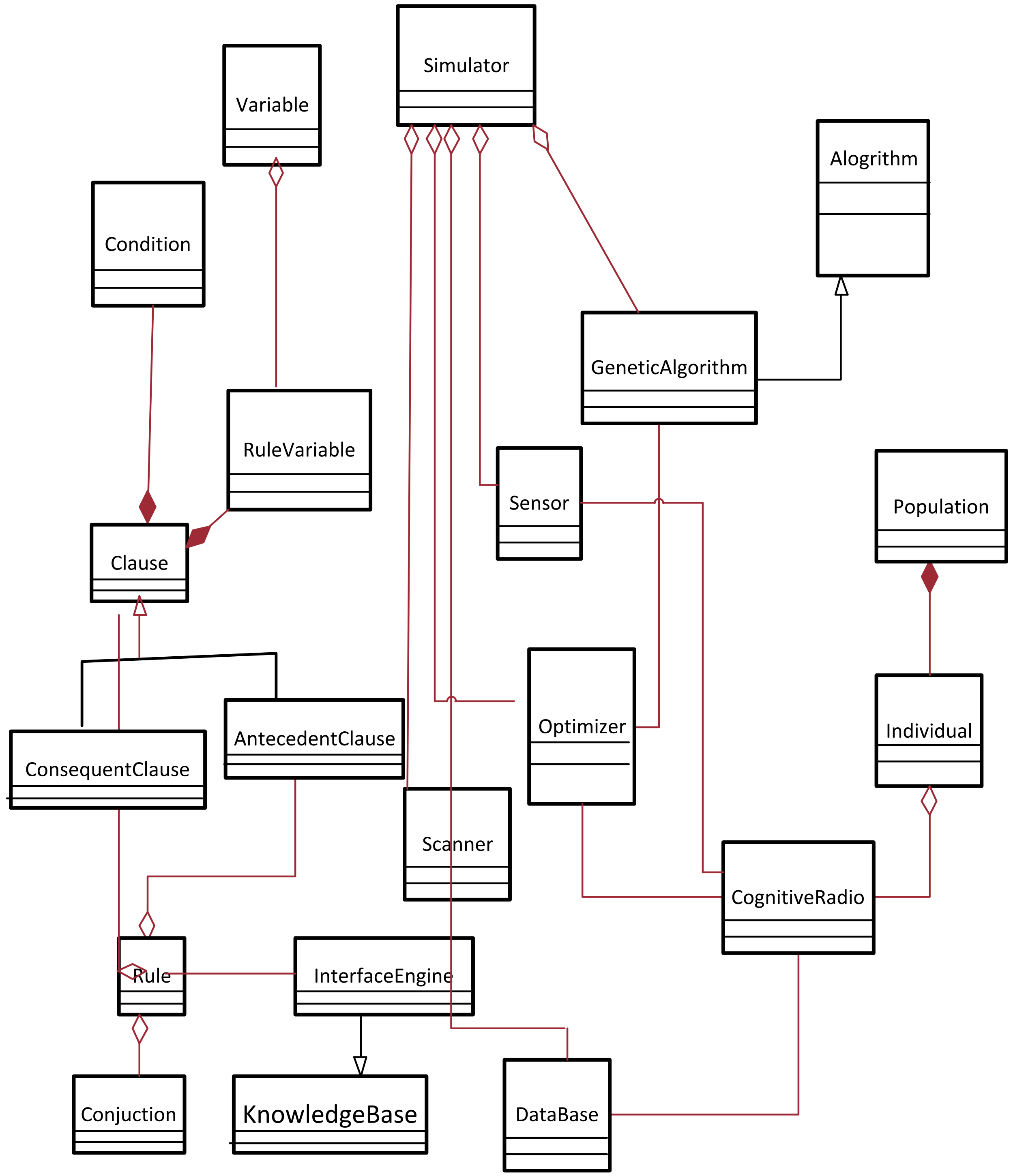


Figure 3.23: Class Interaction Diagram in the new system

3.5.2 Advantages of the New System

The new system has the following advantages

i) The new system will harnessed the potentials of white spaces and improve on its utilization

ii) The new system will harnessed the potentials of Cognitive Radio which will enhance access to unused frequency bands and thereby increase the spectrum utilization more efficiently.

iii) This system will check the availability of the spectrum with spectrum sensing and be able to choose the best available channel which fulfils the secondary users QoS requirements with spectrum detection.

iv) This system will provide information about the available channels for proper access by the white space device

v) The channels will be uploaded and made open for free access by the white space devices.

vi) Coordinate access between the users with spectrum sensing and be able to leave the channel when the primary user is detected with spectrum mobility

vii) The new system will enhance spectrum mobility which is a function related to the change of operating frequency band of CR users.

viii) The new system will be able to reduce the overall detection time which has been the biggest challenge in cognitive radio.

ix) The new system will improve spectrum usage due to the real time exchange of information from the database.

x) Because of the increase in the number of CR users, the probability of finding spectrum holes will reduce drastically with time. CR users will not have to scan a wider range of spectrum to find a hole which will no doubt result in undesirable overhead and system requirements. The proposed geolocation techniques will overcome these challenges.

xi) The new system will enhance performance of the system in the following areas: computational efficiency through concurrency, reliability via redundancy, extensibility of the agency by changing the number and capabilities of the agents, maintainability via modularity and reuse of agents in different agencies to solve different problems.

3.5.3 Justification for the New System

TV white space networks can effectively improve the TV spectrum efficiency and alleviate the spectrum scarcity, and thus is a promising approach to solve the spectrum shortage problem. In a TV white space network, unlicensed wireless devices (called white space devices, WSDs) opportunistically exploit the unused or under-utilized channels (called TV white space, TVWS) in the broadcast television spectrum band. The successful deployment of a TV white space network requires many technical innovations, among which an important one is to reliably detect the available channel and accurately estimate the channel quality at different times and locations. Geolocation database approach as advocated by spectrum regulatory bodies (such as Federal Communication Commission (FCC) in the US and the Office of Communication (Ofcom) in the UK) has been seen as the best approach. In this database approach, unlicensed WSDs obtain the channel information via querying a geolocation database, rather than sensing the wireless environment. Accordingly, the database is required to house an up-to-date repository of TV licensees, and periodically update the channel occupation by TV licensees.

The cognitive radio CR, offers a balanced solution to the problem of spectrum congestion by giving first priority use to the spectrum owner, then allowing others to use the unused portions of the spectrum. To intelligently manage the CR resources, information distribution and sharing becomes very essential and using agents to coordinate and disseminate these information has become necessary in order to ensure a more efficient allocation of spectrum. Hence the proposed system uses database to record the poll of frequencies and locations of the devices. In the CR community, we often talk about cooperation between SUs and negotiation between Primary Users (PUs) and the Secondary Users (SUs).

3.5.4 Justification for the Optimization Technique Adopted

Optimization refers to finding a global maxima or minima of an object function and avoids finding a local maxima or minima (Doyle 2009). For computation problems, an optimum solution is required. For computation problems, an optimum solution is required. But the search towards optimum solution may lead to complications and loss of an important individual because of a very large search space. There are several meta-heuristic techniques to find an optimum solution like particle swarm searches, artificial bee colony searches, firefly searches, hill climbing searches, greedy algorithm searches, tabu searches, simulated annealing searches, and genetic algorithms etc. The main advantage of using a meta-heuristic approach is its tricky nature which really prevents the search space from getting stuck into a local minima or maxima. These techniques can lead to a better solution but for network applications we cannot define an optimum solution in practical words. This is because there is always a possibility that a global maxima or minima may never be found in desired time, and hence almost all network applications are time-dependent therefore the process should be terminated at a given time. Genetic algorithm was adopted this work over other techniques due to its parallelism nature, which of course can really speed up the simulation results.

Due to the generation of a completely new population for each search space genetic algorithm have considerably less chances to get stuck in local extremes as compared to other discussed techniques. Fast convergence is another main advantage of the genetic algorithm and it can converge quickly on a problem's specific solution. Implementation of the GA can be done on semiconductors devices like Digital Signal Processors (DSP) and Field-Programmable gate array (FPGA), and with the help of this it can be integrated with wireless technology.

This easy implementation and re-usage make the GA more significant than other heuristic search schemes. If a basic GA is implemented, then a new object like other chromosomes can be added to it, in order to solve a new problem.

The following are some other significant advantages of the genetic algorithm

i) Continuous or discrete variables can be optimized with the GA.

ii) It doesn't require derivative information.

iii) It can deal with a large number of variables.

iv) It suits well with parallel computers.

v) It does not only provide a single solution but a list of optimum solutions.

vi) It may encode the variables so that the optimization is done with the encoded variables.

vii) It works with numerically generated data, experimental data, or analytical functions.

3.6 Genetic Algorithm (GA)

Since genetic algorithm will be adopted in the proposed system, this dissertation went further to look at the intricacies of genetic algorithm with the view of the reasons for adopting it.

The GA has six basic steps of operation as highlighted in the figure below**.**

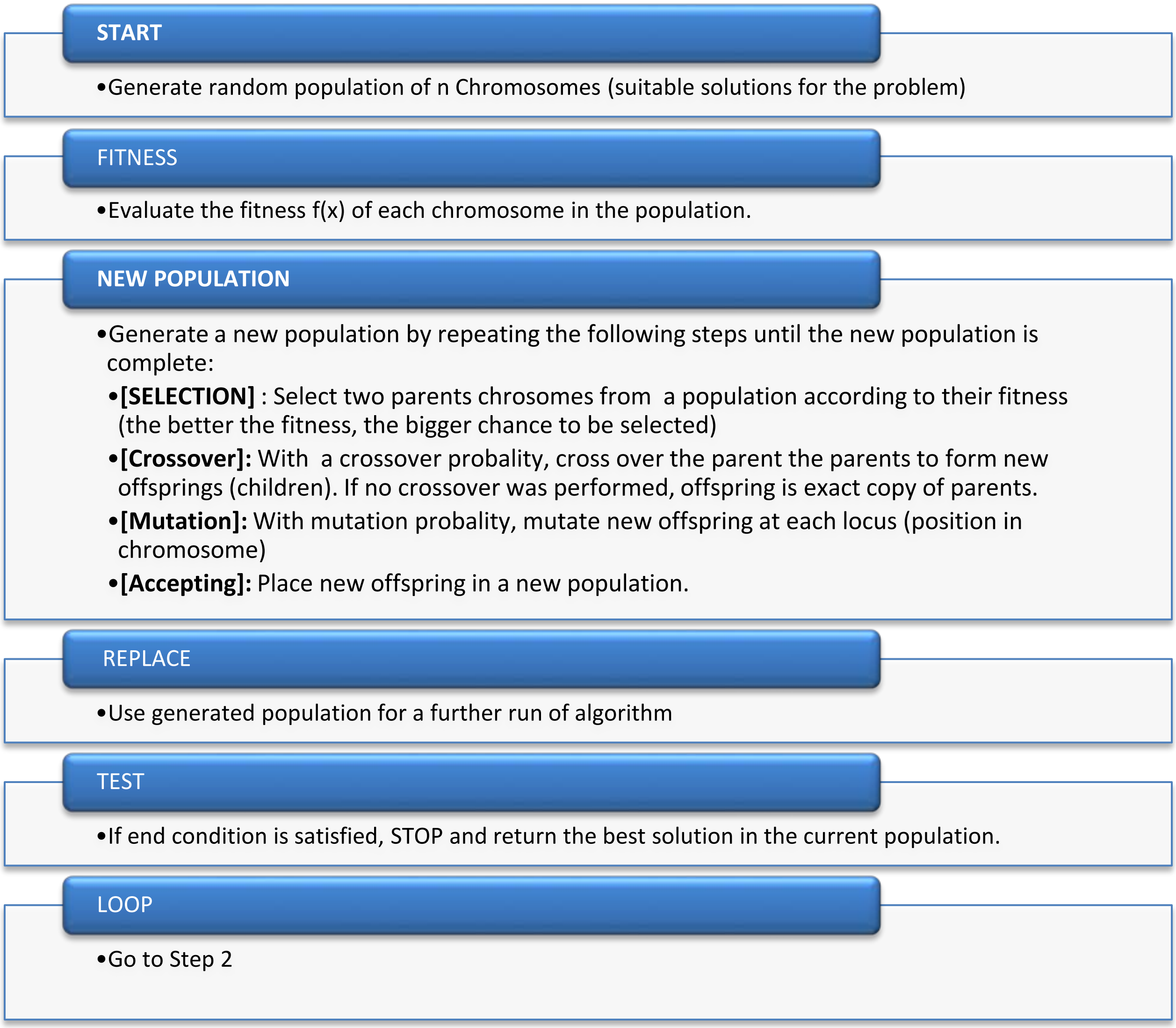


Figure 3.24: An overview of Genetic Algorithm.

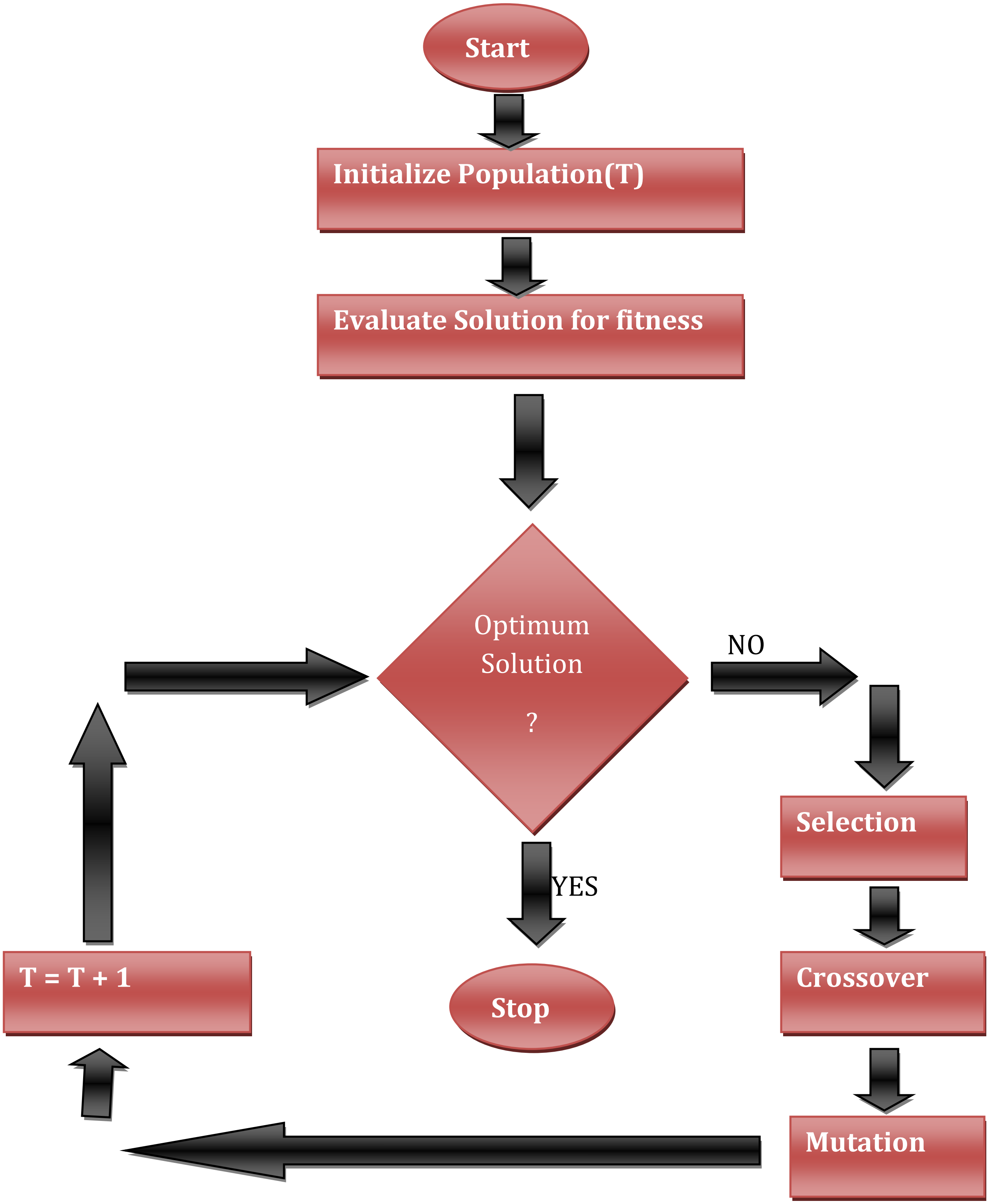


Figure 3.25: A flowchart for Genetic Algorithm

SELECTION

The Roulette-Wheel (RW) selection will be adopted because of its ease of implementation. Here, individual are given a probability of being selected that is proportionate to their fitness. Two individuals are then chosen randomly based on these probabilities and produce offspring. The pseudo-code for RW selection model is given below:

```
For all members of population
        Sum += fitness of this individual
End for
For all members of population
        Probability = sum of probabilities + (fitness / sum)
        Sum of probabilities += probability
End for
Loop until new population is full
        Do this twice
                Number = Random between 0 and 1
                For all members of population
                        If number > probability but less than next probability
                                Then you have been selected
                        End if
                End for
        End do
End loop
```

Figure 3.26: Pseudo code for Roulette Wheel Selection model

CROSSOVER

The single point crossover will be used to produce offspring in our model. Given two parents that have been selected, we choose a locus from which we swap the remaining allele from one parent to the other. The diagram below is used to illustrate this process.

As can be seen from the diagram, both offspring inherited one section of the chromosome from each parent. The point at which the chromosome is broken depends on the randomly selected crossover point. This particular method is called single point crossover because only one crossover point exists. Sometimes only child 1 or child 2 is created, but oftentimes both offspring are created and put into the new population. Crossover does not always occur, however, sometimes, based on set probability, no crossover

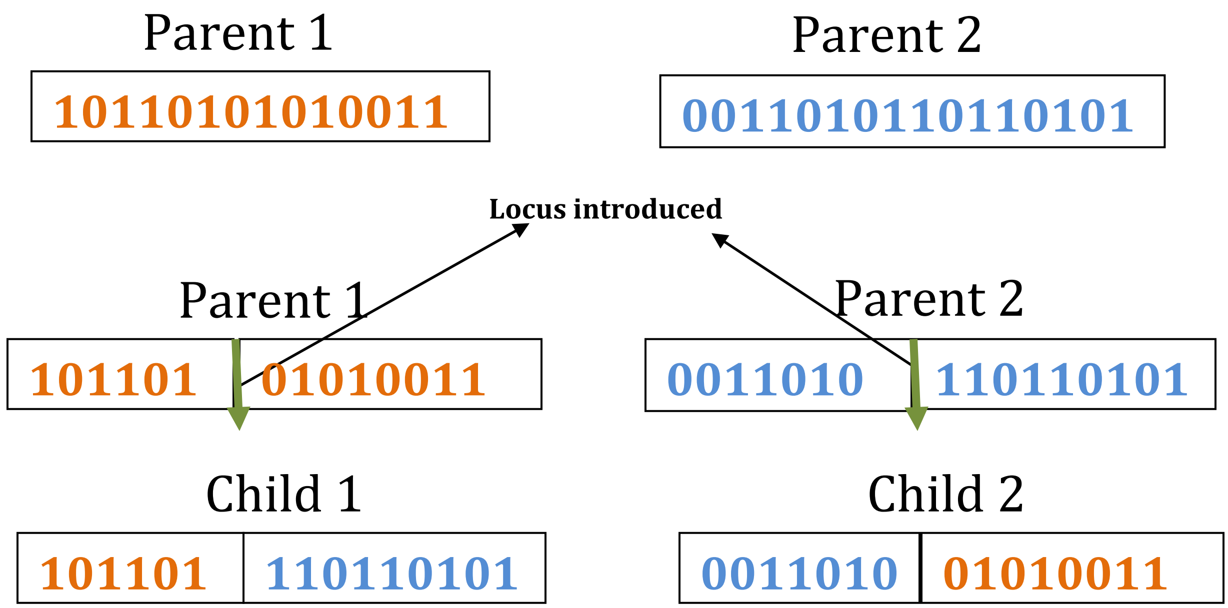


Figure 3.27: A sample Crossover

MUTATION

After Selection and Crossover, we are left with a new population full of individuals. Some are directly copied, and others are produced by crossover. In order to ensure that all the individuals are not exactly the same, we loop through all the alleles of the individuals, and if an allele is selected for mutation, it can be either be changed by a small amount or replaced with a new value. The figure below illustrates the process.

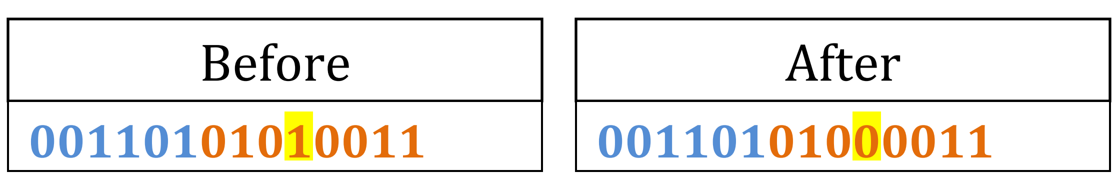


Figure 3.28: Mutation of Child 2

3.7 High Level Diagram of the New System

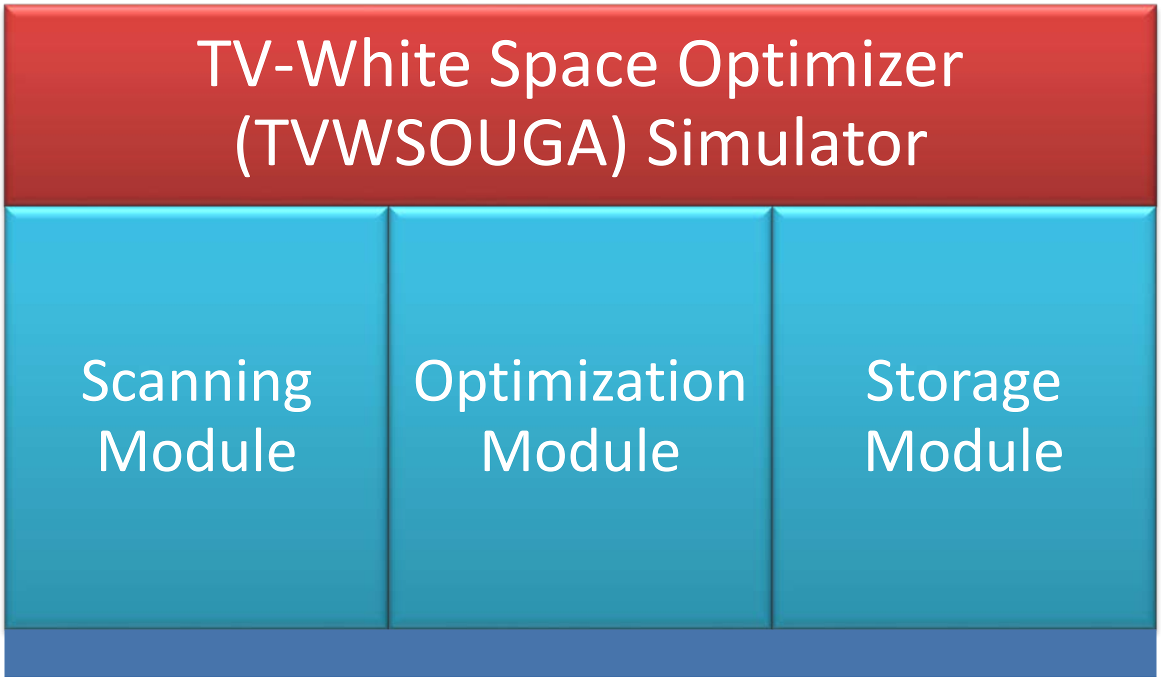


Figure 3.29: High Level Model of the proposed system

The TV-White Space Optimizer has three major components named the scanner, Optimizer and the Knowledge Base

The Scanning Module: is primarily responsible for:

i) Scanning a geographical area for White Space Signal

ii) Detection/ Sensing of White Space Signals and secondary devices

iii) Determination of signal strength of a detected free spectrum

iv) Determination of interference ratio of closest free channels to secondary device.

v) Allocation of free unoccupied channel to detected secondary device.

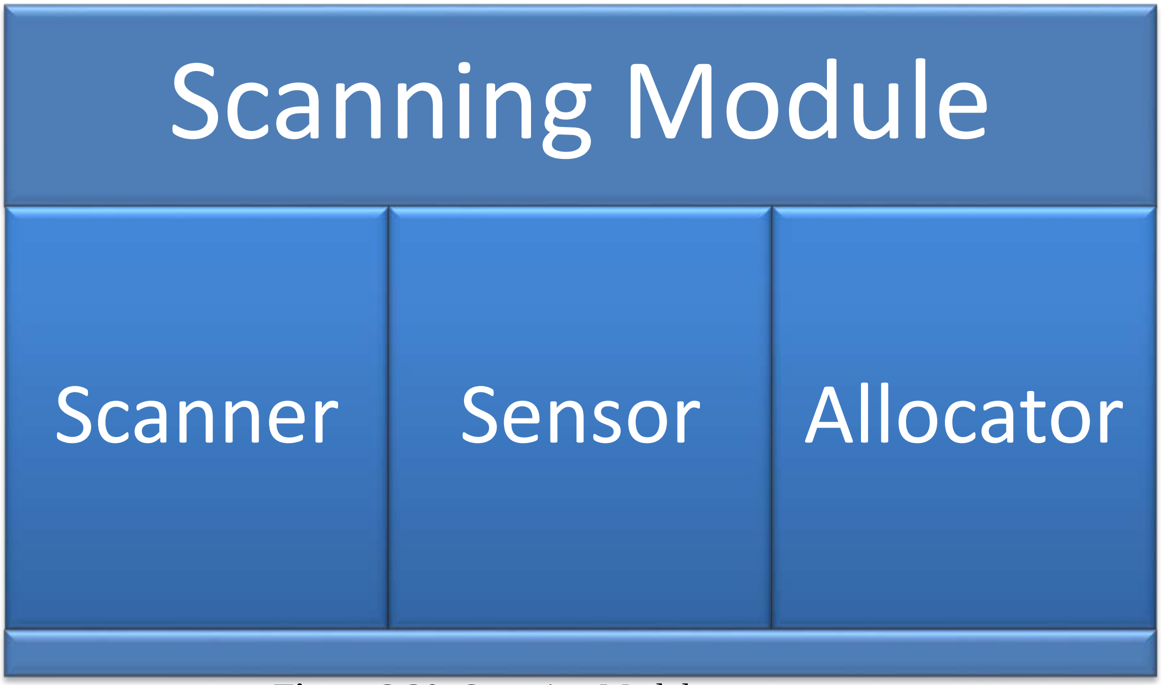


Figure 3.30: Scanning Module

Optimization Module: Uses the Improvised Genetic Algorithm (IGA), Cognitive Radio (CR), Inference Engine (IE), Rule Base (RB), Knowledge Base (KB) and the Data Base (DB) to examine available free and unoccupied channels in order to establish the channel with Highest Signal Strength (HSS), Low Interference Ratio (LIR) with nearest primary/ licensed channel, and subsequently, assign the free and unoccupied channel to a secondary device. This module is made up of the Inference Engine (IE), Cognitive Radio (CR) and the Improvised Genetic Algorithm

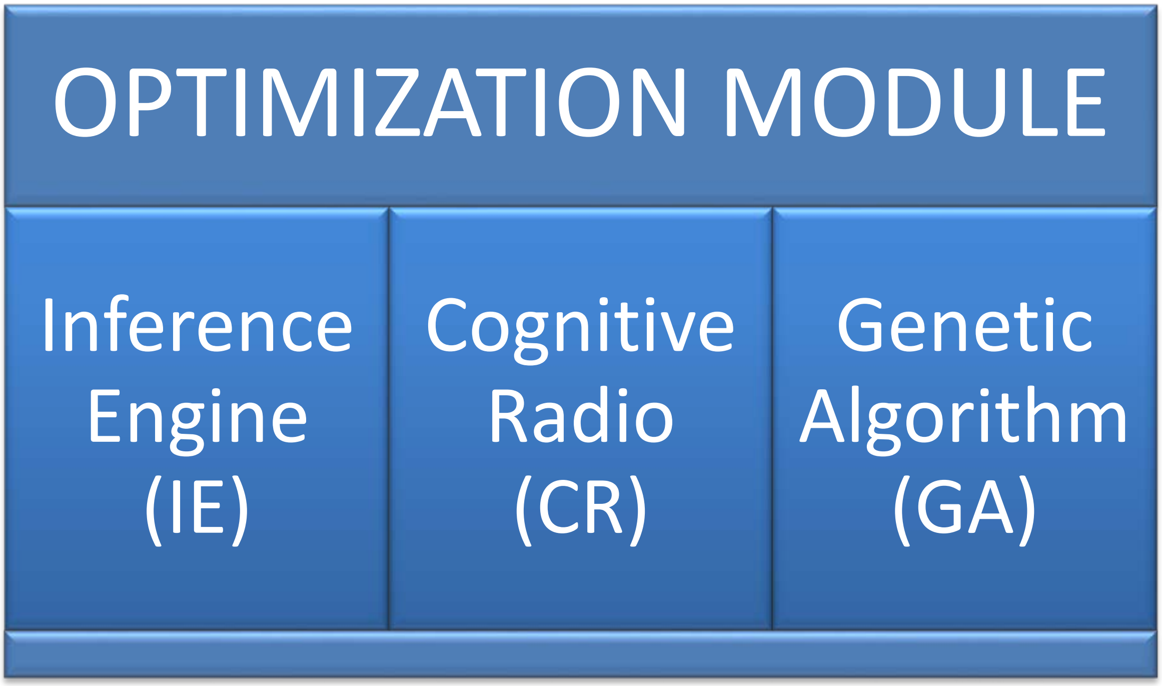


Figure 3.31: Optimization Module

Storage Module

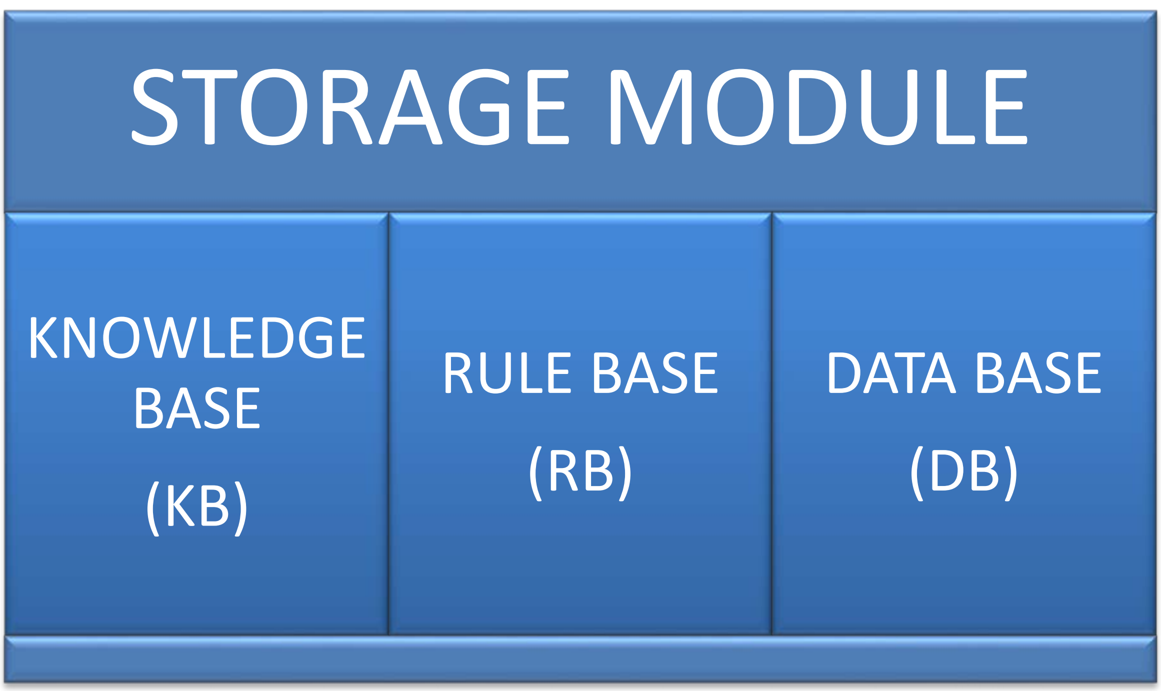


Figure 3.32: Storage Module

The storage module is made up of the Knowledge Base (KB), the Rule Base (RB) and the Data Base (DB). These objects combined together, store the information needed for any agent or object instantiated within the context of our proposed system. For instance, a Cognitive Radio (CR) object will scan the Knowledge Base (KB) and the Database (DB) with the help of a Scanner object in order to get details of Adjacent Channels, transmitting radius, transmitter power, current location, signal strength.

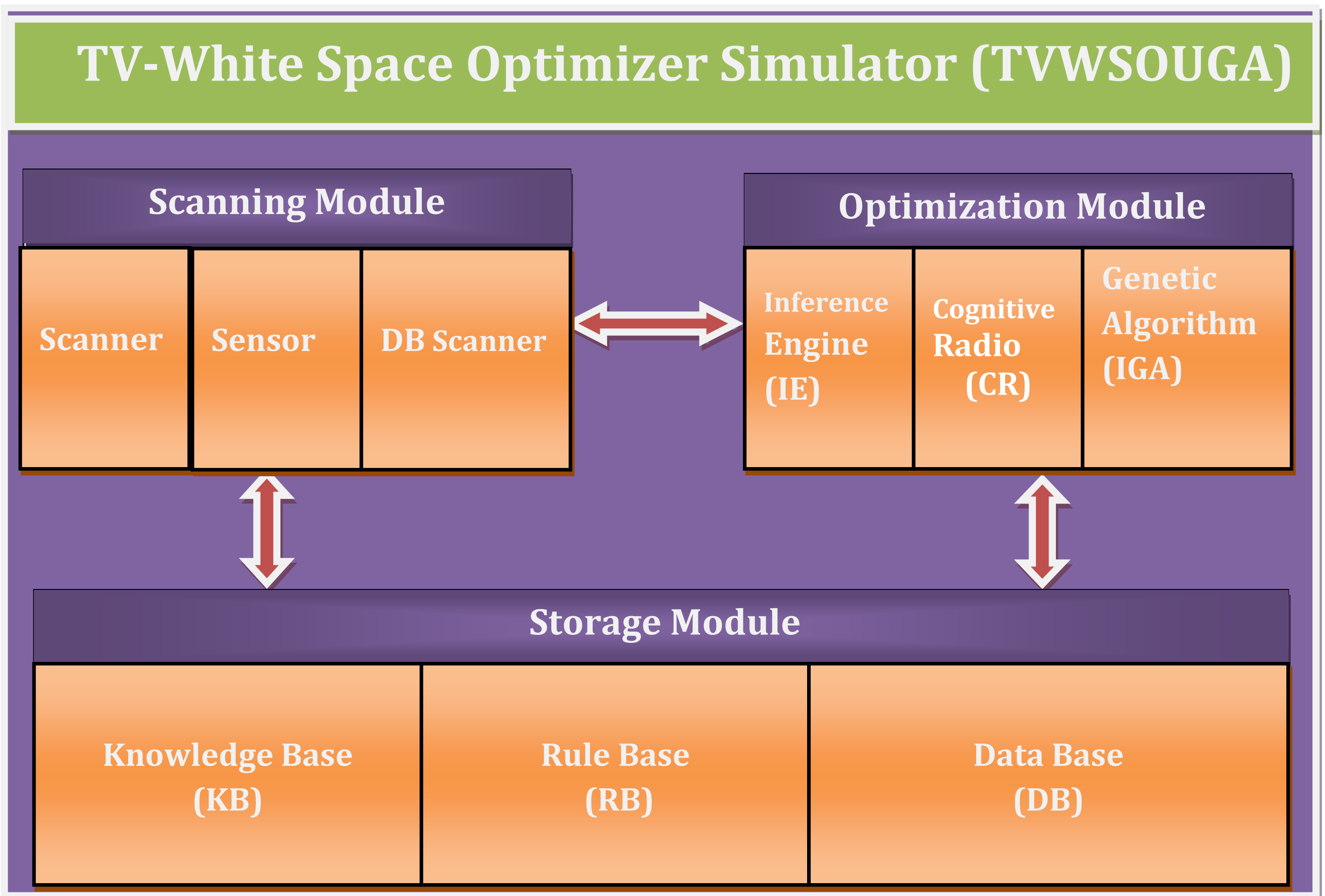


Figure 3.33: High Level Model Diagram/Architecture of the New System.

CHAPTER FOUR

SYSTEM DESIGN AND IMPLEMENTATION

4.1 System Design

Several researchers have pointed out and demonstrated the enormous benefits of using whitespaces by having secondary users utilize them for other uses instead of allowing them to be wasted. But they did not use any optimization technique to find an optimized whitespace for a particular user at a particular location using a particular whitespace device. In order to improve on other researchers work, we intend to treat the problem as an optimization problem seeking to maximize and optimize the quality of service delivery of the whitespace to the user concerned in order to effectively utilize the available whitespaces. The potential secondary user device looks for the quality of service (signal strength) for the available whitespaces detected, taking into consideration the whitespace device used and the location of the user. The user device must then select the whitespace with a higher quality of service but with the least interference. The model for whitespace utilization must be remodeled to take note of these quality requirements so as have improved model that would maximally exploit the usefulness of whitespaces in the country.

In this work, we seek to employ and use Genetic Algorithm in modeling, improving and optimizing the rule based systems to find an optimized white space that can serve the user effectively. Our proposed system models the users explicit and implicit parameters of the white spaces for an optimally service delivery using a rule base approach.

Secondly, we intend making use of Genetic Algorithm to optimize the control structure and allocation of the available white space to requesting WSDs in the locations under consideration

In our design, we considered the fact that white space devices using cognitive radio frequencies regarded as secondary users or unlicensed users sometimes fall victims of interferences from the primary (licensed) users of that frequency. This prompted inclusion of good sensing algorithm to reduce interference. This design in addition optimizes the use of the available white spaces by using geolocation technique to overcome interferences of aforementioned scenario and to increase the sensing ability of the cognitive radio in identifying free channels that are not utilized.

4.2 Objectives of the Design

(i) The objective of this design is to develop algorithm that will sense the availability of spectrum within the white space in the location of interest.

(ii) The design will also simulate a software that will identify locations of white space devices and their broadcast radios to determine likely interferences before it occurs

(iii) To create a central logging system to register location and broadcast radios of white space devices as well as primary user’s frequency status to ensure even distribution of information.

(iv) Modify the High Level Model (HLM) in section 3.7 to incorporate Graphical User Interface concerns.

(v) Design the graphical user interface as specified in the enhanced HLM.

(vi) Design the Database and Knowledge Base of the new system

4.3 Design Conceptualization

The design of this work considered devices that are classified as unlicensed or secondary users, frequency availability. Here a user will need to make request and try to use the best available frequency with good response time. The chromosome for the improvised genetic algorithm will be formulated using the following:

i) Device Type
ii) Signal Strength
iii) Location of the device/user
iv) White Space availability
v) The location
vi) Broadcasting Status

The design aim is to utilize the White Spaces in the TV band for unlicensed devices because of the proliferation of devices under this category. It aimed to satisfy a set of functional and non-functional requirements (NFRs). In general, functionality is the key for selecting the appropriate candidates for service composition. However, in the case where existing services (licensed users) have the same functionality but different non-functional properties (NFPs) that is the unlicensed users, the first should be considered in order to best satisfy the overall NFRs. Figure 4.1 below shows the a proposed conceptualize design.

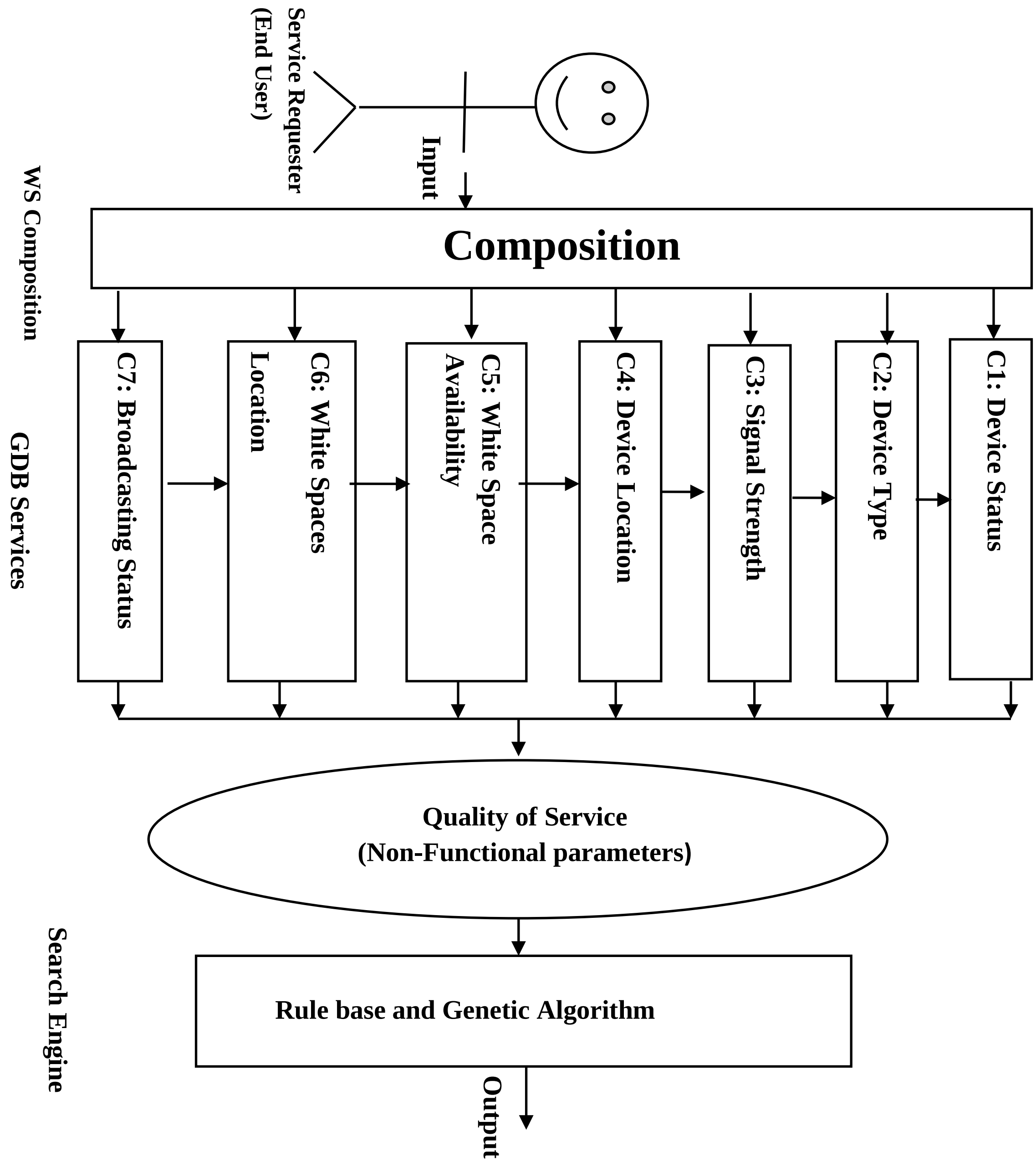


Figure 4.1: A New Conceptualize System Model

4.3.1 Design Logic

The composition of Quality of Service (QoS) properties is done with the help of rule base and fitness function based service selection. Figure 4.2 shows the new system architecture of the optimized White Spaces selection:

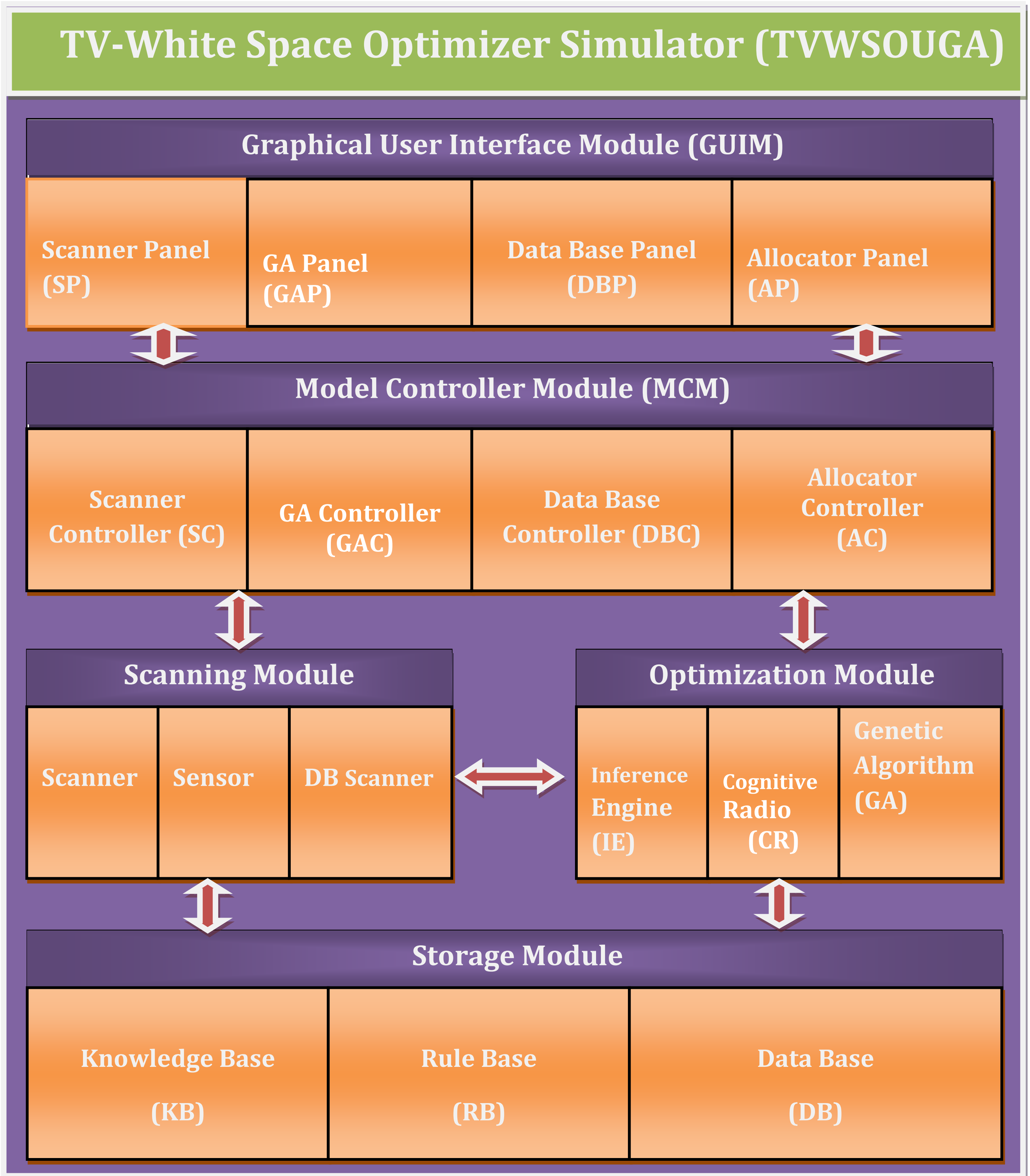


Figure 4.2: Enhanced High Level Model Diagram/ System Architecture of the new System

4.4 Control Centre / Main Menu

The control centre for the new system is divided into three; the scanner, location and channel mode the main menu for the scanner, selecting the available channels to be used by the WSD this is the first operation to be done, compute the fitness base on the inference rule conditions. The main menu for the TVWSOUGA includes home, GA console, Graphs Tables and Logout. The main menu is shown in figure 4.3.

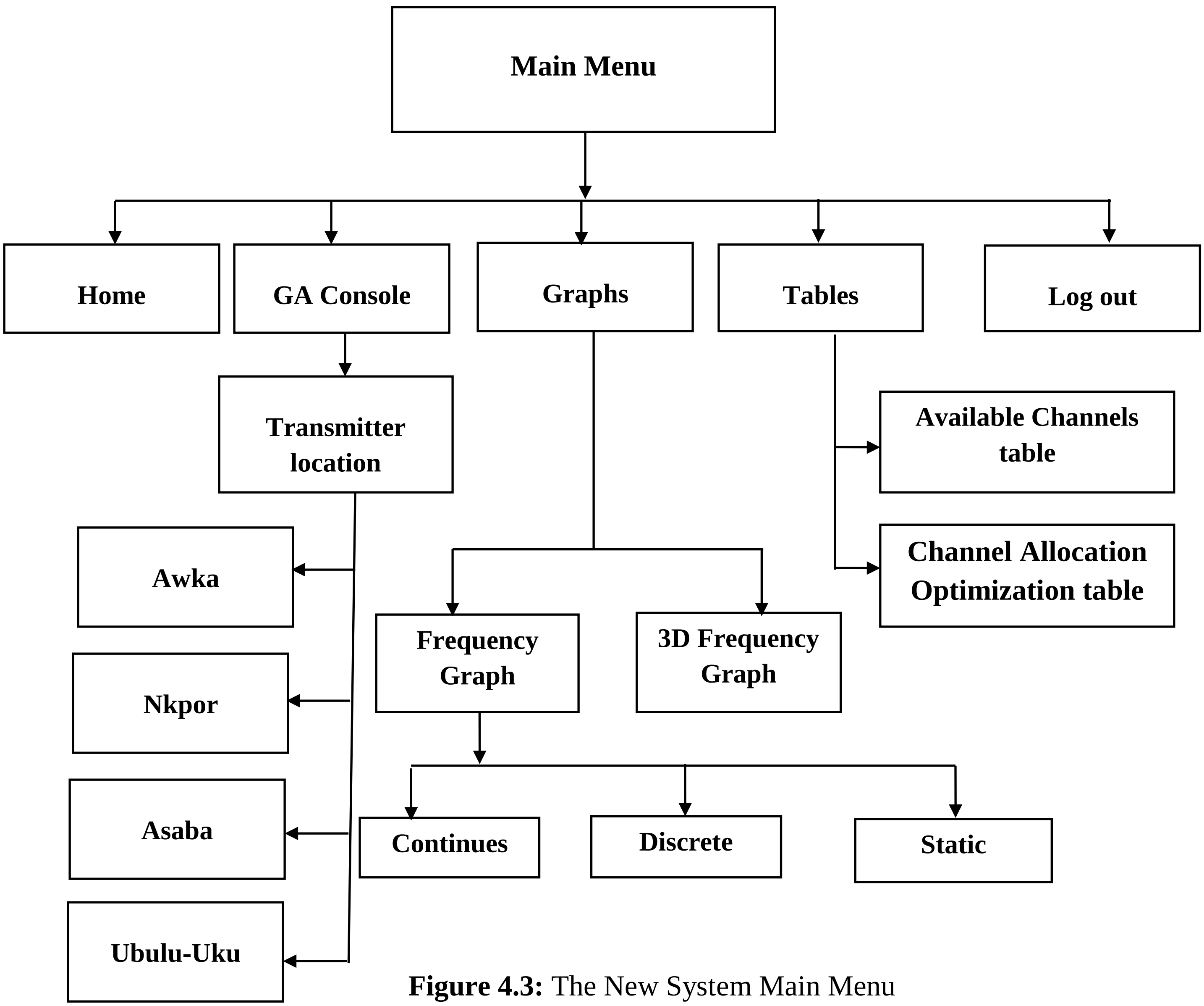


Figure 4.3: The New System Main Menu

4.4.1 The Submenus/Subsystems

The submenus for the new system include:

i. **Home**: This sub module when selected displays the home page of the new system.
ii. **GA Console**: This sub module displays the transmitter location. Four locations are under consideration namely Awka, Nkpor, Asaba and Ubulu-Uku.
iii. **Graphs**: This sub module displays the frequency graph both in continuous, discrete and static as well as in 3-dimensional format. The scanning of the different channels availability is calculated in this module.
iv. **Tables:** This sub menu handles the information on the available channels and also shows the channel allocation optimization.
v. **Log out:** This sub menu is used to log out when the user finishes all he/she want to do with the system.

Subsystems

User Interface: - The white space device should be able to sense the spectrum by communicating with the Geo-location Database (GDB). It is an automated process since the user must first indicate the use of a whitespace. This is where the geo-location database serves a great deal in this work. The geo-location database contain information about each spectrum, such as available whitespace at any point in time, the status of the primary user for that spectrum both licensed and unlicensed spectrums, the quality of services parameters just to mention but a few. This geolocation database locates appropriate whitespaces using the requirements and selection criteria.

i) GDB contains information about the white spaces, it also register and keeps device information

ii) GDB provide directory for storing information about the White Space Devices (WSD) in that location, the information include: Device name, Device ID, specification, coverage radius, device status (ON, OFF or Broadcasting)

iii) GDB provide directory for White Space Agents

iv) It provides format for communication between devices

White Space Availability: Checks and communicate the frequencies available in the considered location while monitoring interference.

Device Type: Locate and describe the type of device that is communicating in any given time and its characteristics.

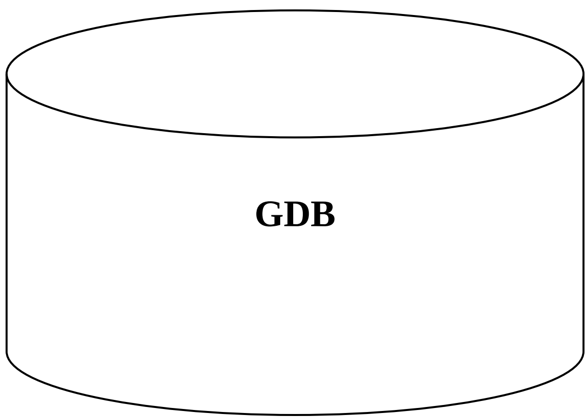


Figure 4.4: Geolocation Database System

Inference Engine (IE):**-** This is a very important component of the proposed system as it does the reasoning/or make decision using the rules stored in the knowledge base (KB). It is the brain of the system. It does this task by

i) Acting like a search engine examining the Knowledge Base for information that matches the user's query (question).

ii) It uses the query to search the Knowledge Base and then provides an answer or some advice to the user.

iii) It also utilizes the contents of Knowledge Base in conjunction with the data given by the user in order to achieve a conclusion.

Inference Rules (IRs): All the contributions and combinations of the rules are aggregated or summed using the Max-Min inference rules techniques.

i) This technique is used to calculate numerical results of the linguistic rules based on the system input values.
ii) This is where all generated rules are evaluated.

Max-Min inference rule base approach is used in solving the control (IF-THEN rules) problem mathematically rather than attempting to model the system – without obtaining an optimal set of rules.

Knowledge Base (KB): This is the most essential module of the system. It is referred to as the heart of the system. It contains and stores all data, information, rules and constraints used by inference engine for solving difficult problems or tasks. In the proposed system, the knowledge base comprised of two components:

i) Data Base (DB), containing the definitions of the scaling functions of the variables and
ii) Rule Base (RB), constituted by the collection of rules. A collection of rules used in the knowledge base of a system. It has an IFAND/OR-THEN structure.

The performance of a rule based system depends largely on the control (IF-THEN rules) structure and selection of the Knowledge Base. Optimization of the Knowledge Base is critical to the performance of the system. GA provides such a method to optimize the rule based parameters.

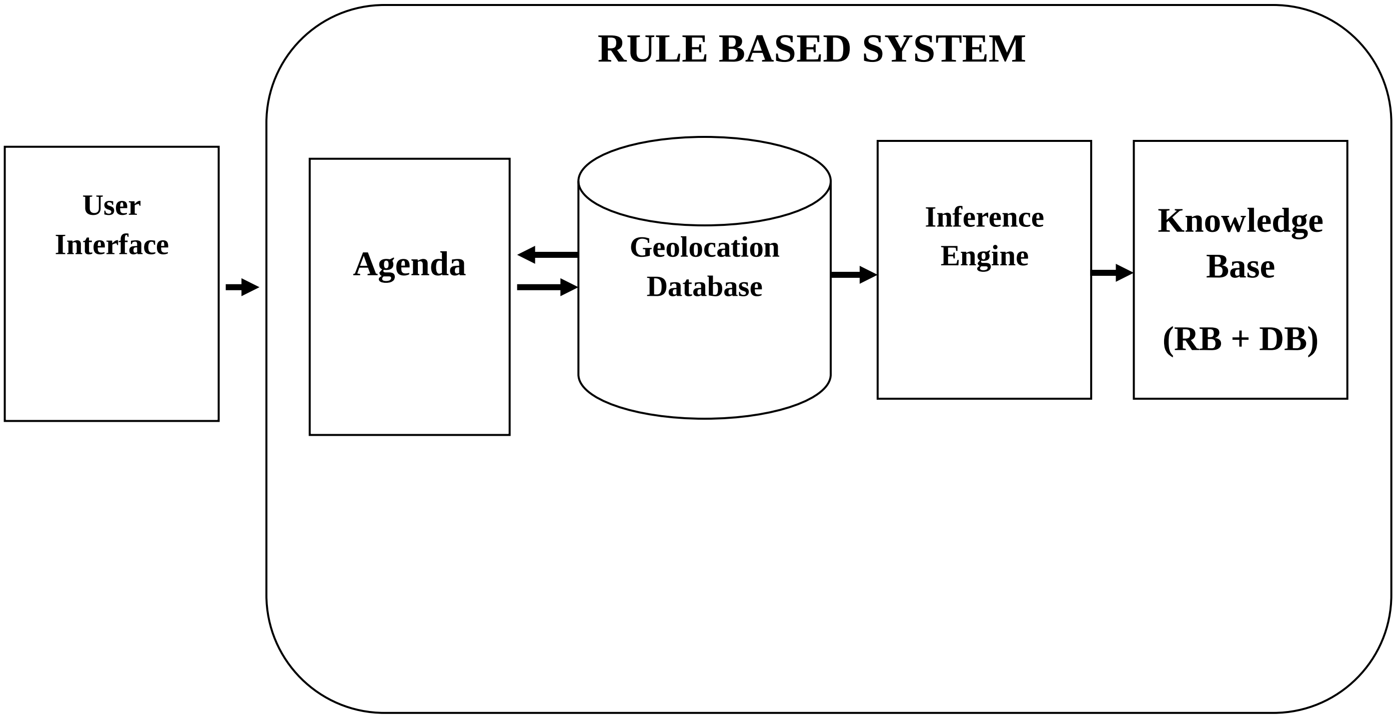


Figure 4.5: The Rule Based System for selection of white Spaces

GA Optimization Process: the GA is used for improving and designing the rule based system such as optimizing the system variables for an optimized solution. Thereafter, an optimized solution is selected in accordance with the user's preferences. Optimization refers to finding the best solution to a problem. Here, best refers to an acceptable (or satisfactory) solution, which may be absolute best over a set of candidate solutions, or any of the candidate solutions.

It is worth mentioning that the objective of resource allocation problem is to minimize the response time which heavily depends upon the execution time of the scheduling algorithm. Here, the enhanced genetic algorithm which we believe will reduce the execution time and also concentrate on improving the resource utilization rate by equally distributing the load is employed in this design.

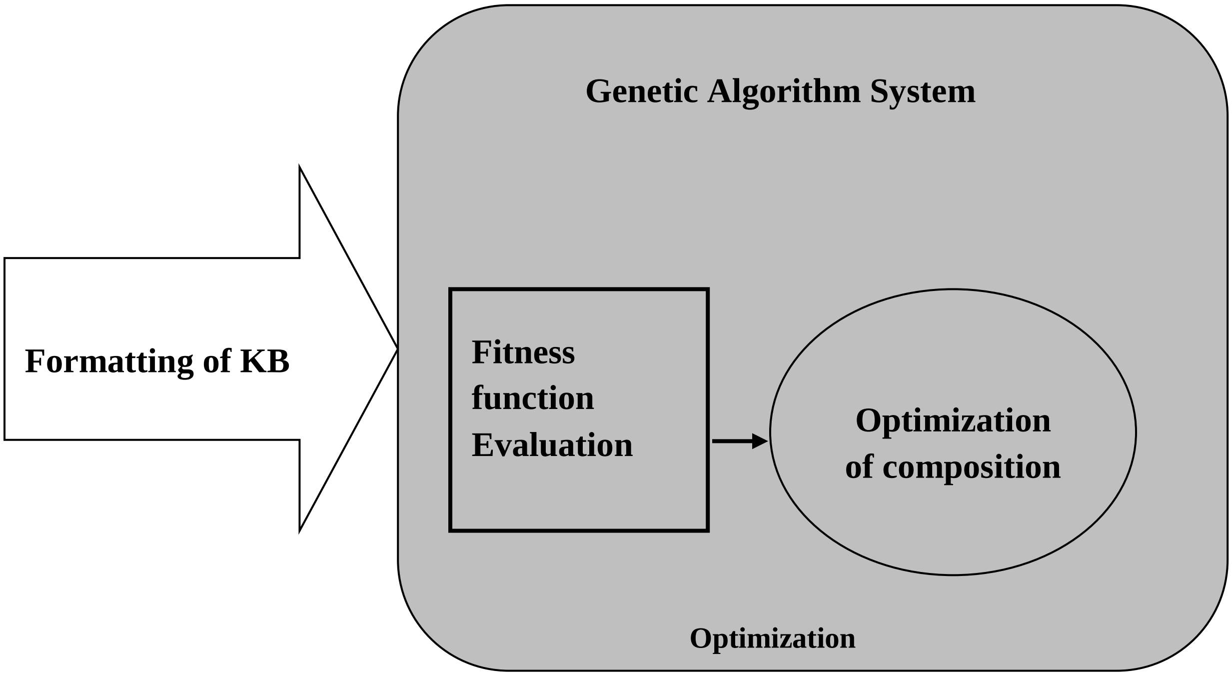


Figure 4.6: Genetic Algorithm System for White Space Optimization

4.4.2 Knowledge Base Design

As stated earlier the knowledge base is the most essential module of the rule based systems. It contains and stores all data, information, rules and constraints used by inference engine for solving difficult problems or tasks. The rules in our knowledge base were carefully chosen in conformity with the problems will intend solving.

The number of rules generated in this research work was based on equation 4.1 as presented by Alavala (2012)

$$\text{Number of Rules} = C_i^x \qquad 4.1$$

Where Ci is the number of allocation classifiers and x is the number of inputs. The generated rules for this research are shown in Appendix IV.

4.4.3 GUI Module Class Relationship Diagram

The graphical user interface module is shown in figure 4.7 with the scanning, database and allocation panel for the new system.

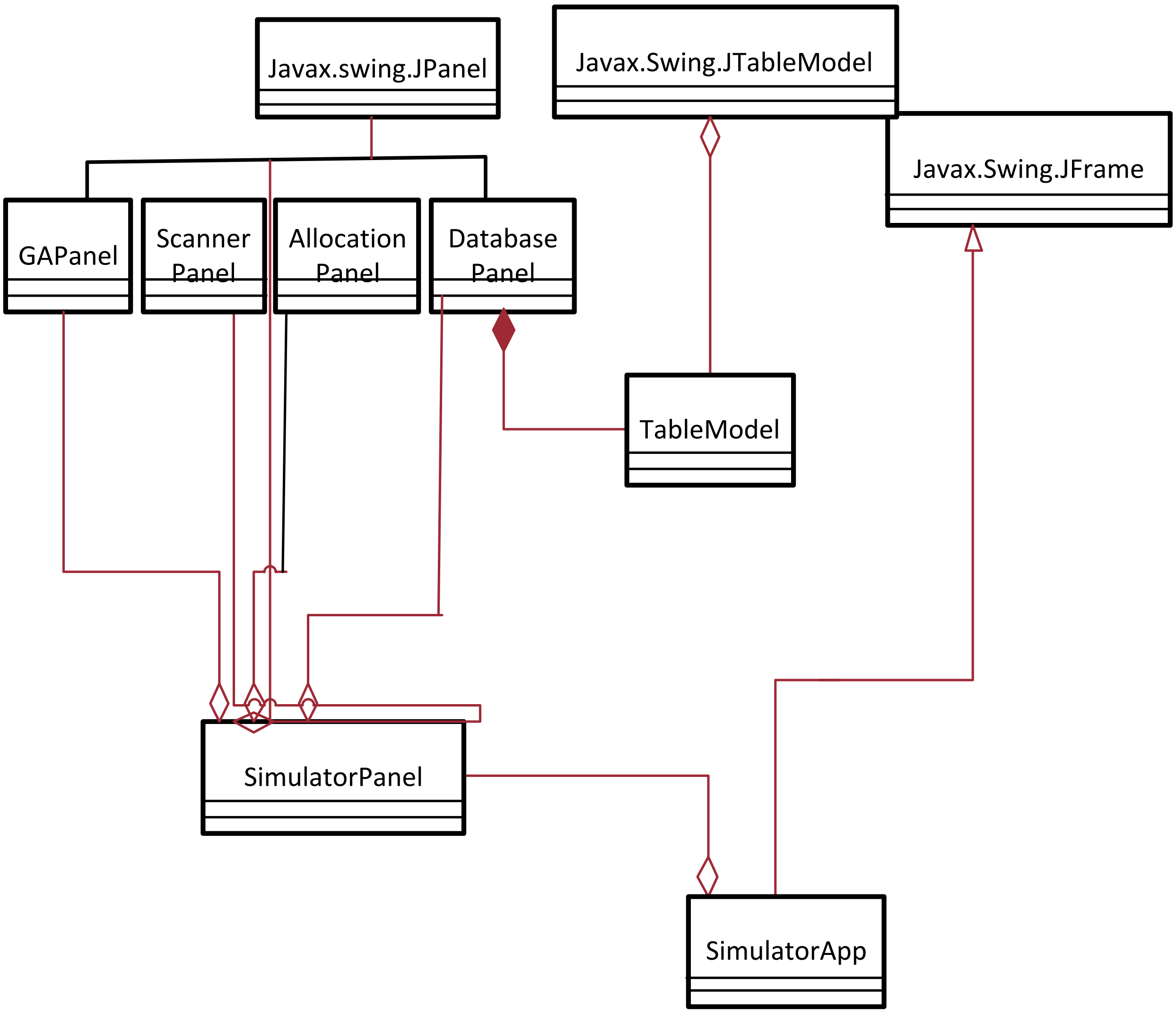


Figure 4.7: GUI Module class Relationship Diagram

4.5 System Specification

The system specification describes the ideal specification for the new system to function optimally. The system specification details are shown in Table 4.1:

Table 4.1 The New System Specifications

System specification	**Descriptions**
Software applications to be used	These include off-the-shelf applications modified to suit the new system such as Java Run Time Environment (JRE) release 8 or later version on the machine that will run the application
Storage requirements	This includes local storage requirements such as hard disk size or it may be networked storage such as file servers
System memory	How much RAM will be required by the system in order for it to run effectively
Input devices needed	These include Mouse, Keyboard, spectrum analyzer, DBT-2
Output devices to be used	These include printers, speakers, visual display unit of 15.6”
Computing/ processing power needed	A standard personal computer with core i3 processor with processing speed of 1.2GHz or higher will be able to access this system
Security and Backup systems	User accounts with rules to be created and maintained by the database administrator
People required	A Database Administrator is needed to update changes to database. It has to be a skilled personnel
Buildings and offices required	The application will be deployed at the base station of terrestrial TV network providers.
Network configuration	Transmitter with transmitting power of 100W, 300W, 600W or more and receiving antenna gain of 12dB,

The overall purpose of the system specification documentation is to lay down exactly how the system is made up.

4.5.1 Database Development Tool

The database development tool used is MySQL, a web server known as Apache was used to connect the MySQL database. This was employed for easy saving of data analyzed from different locations in this work. Also PhPMyAdmin was used in accessing the database. All these were employed to illustrate the independent nature of the new Tv white space optimization system. Some of the specific development tools include:

i) Create/alter table: Tables were created for channels information in each location; also allocation tables in each location and user table were created.

ii) Channel Allocation table: both the available and the allocation table can be viewed by the administrator and the users.

iii) Rule table: the different rules in the knowledge base for the allocation of the best channel are created in this table.

iv) Clause table: the different conditions considered fit for a channel to be allocated WSD is created in this place

4.5.2 Database Design and Structure

TVWSOUGA is made up of the following tables

Table 4.2: Rule Table

TABLE NAME: Rule			
SN	FIELDS	DATA TYPE	REMARK
1.	Rule_id	VARCHAR	PRIMARY KEY
2.	Clause_id	VARCHAR	PRIMARY KEY
3.	conjunction	Enum(‘AND’,’OR’,’IMPLICATION’)	

Table 4.3: Clause Table

TABLE NAME: Clause			
SN	FIELDS	DATA TYPE	REMARK
1.	Clause_id	VARCHAR	PRIMARY KEY
2.	Rule_variableid	VARCHAR	PRIMARY KEY
3.	condition	Enum(‘AND’,’OR’,’IMPLICATION’)	
4	Clause_type	Enum(‘ANTECEDENT’,’CONSEQUENT’)	
5	value	VARCHAR	

Table 4.4: CRDB Table

TABLE NAME: CRDB			
SN	**FIELDS**	**DATA TYPE**	**REMARK**
1.	CR_id	VARCHAR	PRIMARY KEY
2.	DBC	Enum(‘0’,’1’)	
3	PIB	Enum(‘0’,’1’)	
4.	POOB	Enum(‘0’,’1’)	
5.	CNR	Enum(‘0’,’1’)	
6	PR	Enum(‘0’,’1’)	
7	EL	Enum(‘0’,’1’)	
8	DBSS	Enum(‘0’,’1’)	
9	CRUE	Enum(‘0’,’1’)	
10	CRLocation	Enum(‘0’,’1’)	
11	Adjacent_CR	Enum(‘0’,’1’)	
12	Adjacent_CR_Direction	Enum(‘0’,’1’)	

Table 4.5: Chromosome Key

S/N	Key	Meaning
1	DBC	Database Channel
2	PIB	Power in Band
3	POOB	Power out of band
4	CNR	Carrier Noise Ratio
5	PR	Protection Ratio
6	EL	Emission Limit
7	DBSS	Database Subscriber Station
8	CRUE	Cognitive Radio user Equipment

Table 4.6: Available Channel

S/N	Field	Type	Collation
1	ID	INT(50)	
2	BAND	VARCHAR(50)	LATIN1_BIN
3	CHANNELNO	VARCHAR(50)	LATIN1_BIN
4	STATUS	VARCHAR(50)	LATIN1_BIN
5	LOCATION	VARCHAR(50)	LATIN1_BIN

Table 4.7: Channel Allocation

S/N	Field	Type	Collation
1	ID	INT(11)	
2	BAND	VARCHAR(12)	LATIN1_SWIDISH_CI
3	CHANNELNO	INT(11)	
4	STATUS	ENUM(‘RESERVED’,’FREE’ ,’OCCUPIED’)	LATIN1_SWIDISH_CI

5	LOCATION	VARCHAR(100)	LATIN1_SWIDISH_CI
6	ACTION	VARCHAR(249)	LATIN1_SWIDISH_CI

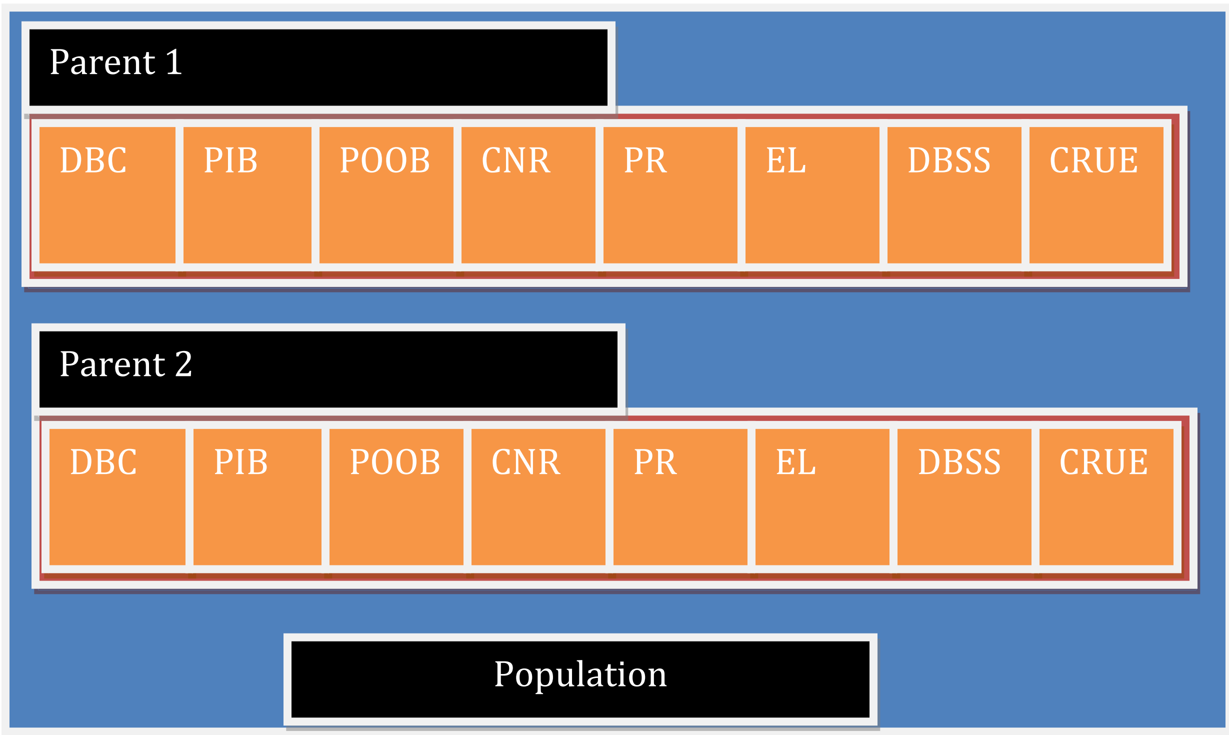


Figure 4.8: Population Schematic

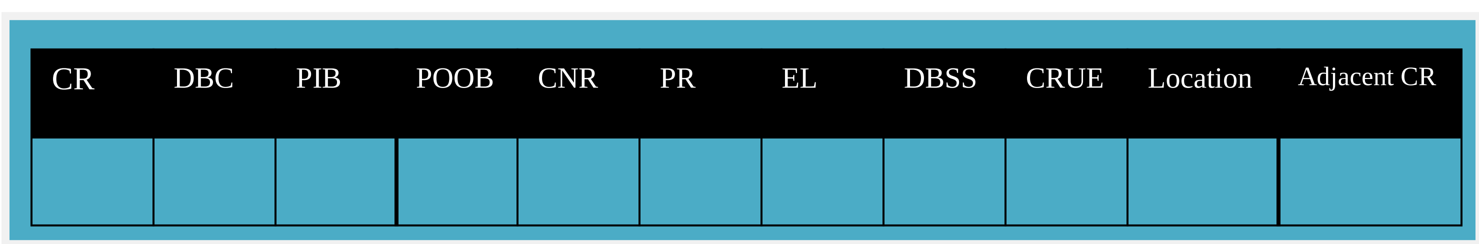


Figure 4.9: Database Panel

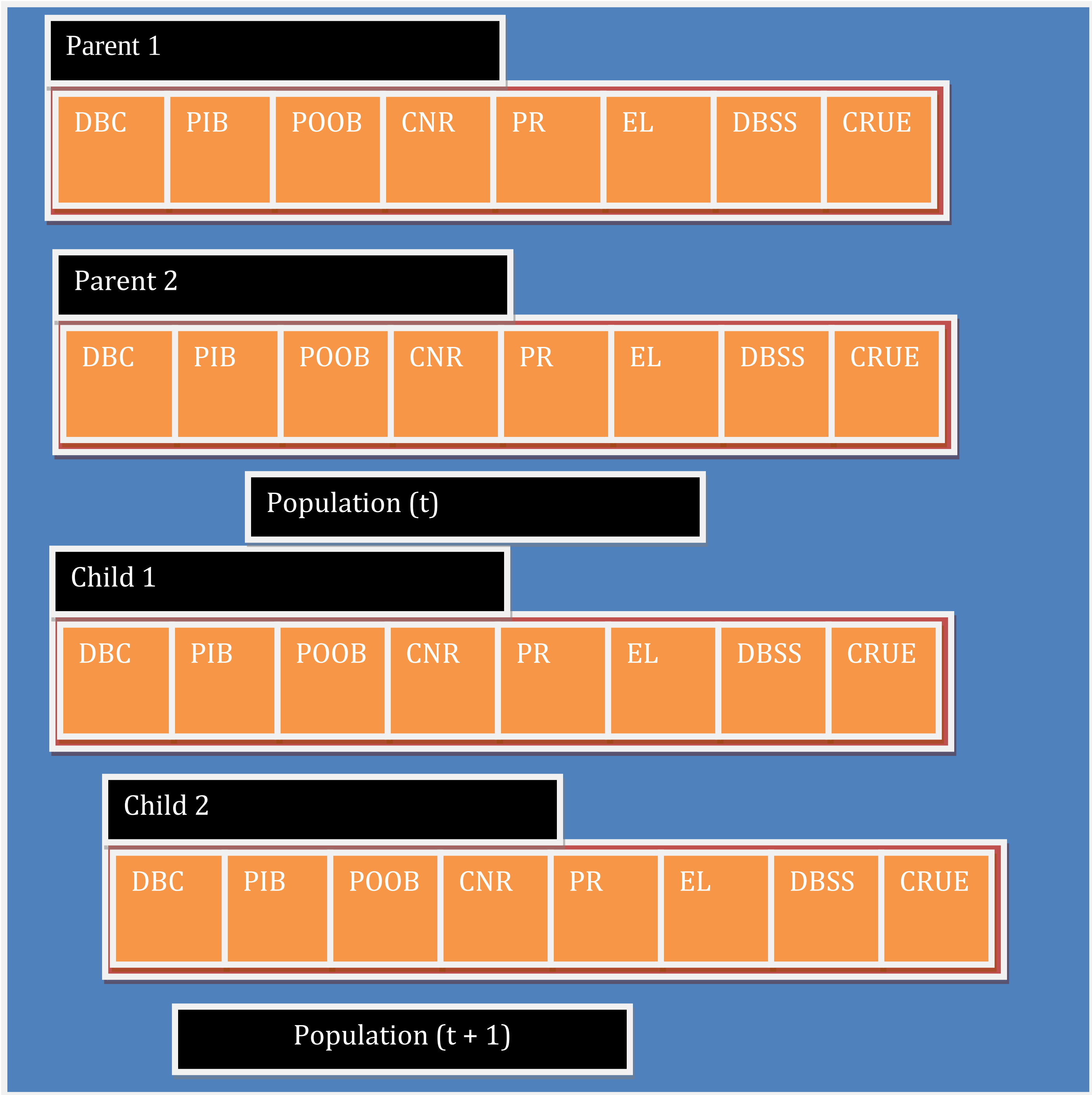


Figure 4.10: GA Panel

4.6 TV White Space Optimization Model

Genetic algorithms evaluate the target function to be optimized at some randomly selected points of the definition domain. Taking this information into account, a new set of points (a new population) is generated. Gradually the points in the population approach local maxima and minima of the function. Adopting the genetic algorithm proposed by Rojas (1996), we can optimize channel selection for the WSDs. More so he affirmed that genetic algorithms are stochastic search methods managing a population of simultaneous search positions. In this dissertation, the three essential elements of conventional Genetic Algorithm (GA) proposed by Rojas were employed which comprises of:

- Selection
- Cross Over/ Recombination
- Mutation/ Value Flipping

Therefore the probability ***P*(GA)** of our Genetic Algorithm (GA) being correct is given by the probability of the selection method ***P*(S)** and the probability of the Cross Over method ***P*(C)** and the probability of the mutation method ***P*(M)** all being correct. This assertion can be stated mathematically as:

$$P(GA) = P(H) + W + W' \qquad 4.2$$

Where

P(H) = Probability of selection

W = Probability of selection X Probability of survival

W' = Probability of selection X Probability of survival X Probability of Mutation

For crossover (W), a random choice is made, where the likelihood of crossover being applied is typically 60 percent and above (Kumar 2012).

In order to achieve the desired goal of this research, the three probabilities were mutually exclusive.

Given that the binary chromosome where the genes are a combination of binary bits 0 or 1 is adopted in this dissertation.

In our algorithm, the population is made up of a set of ***N*** binary strings of length, ***l*** at a time ***t***. We call a string of length *l* which contains one (1) of the three symbols 0, 1 0r * in each position a *bit pattern* or *schema, where * is either a 1 or a 0.*

A further look at equation 3.25, one can deduce that the probability P(GA) of our Genetic Algorithm producing the required bit pattern is equivalent to the probability of the child string containing the required bit pattern after mutation. This translates equation 3.26 to:

$$P(GA) = W' \qquad 4.3$$

The following terms used are define

n(H,t) **–** This tells the string at a particular time t

o(H) – This is the number of fixed position bit in the schema

δ(H) – This is the defining length of the schema. It is the length or distance in between the 1st and the last fixed position

f_μ – This represent the mean of the fitness of the population.

The number of strings in a population in a given generation ***t*** which contains the bit pattern ***H*** is given by ***n(H, t).***

As we know, two parents' strings from the current population are always selected for the creation of a new string.

The probability that a parent string H_i will be selected from N strings $H_1, H_2, \ldots, H_N$ is given by

$$P(H_i) = \frac{f(H_i)}{\sum_{j=1}^{N} f(H_j)} \qquad 4.4$$

This means that strings with greater fitness are more likely to be selected than strings with lesser fitness.

The average fitness (f_μ) of all strings in the population is given by

$$f_\mu = \frac{\sum_{j=1}^{N} f(H_j)}{N} \qquad 4.5$$

Where N is the number of string

From equ 4.4 and 4.5 we have equ 4.6

$$Nf_\mu = \sum_{j=1}^{N} f(H_j) \qquad 4.6$$

We now rewrite equ 4.4 as

$$P(H_i) = \frac{f(H_i)}{Nf_\mu} \qquad 4.7$$

Equ 4.7 helps to give the expected count of the string that will enter the mating poll.

Therefore the probability that a parent string H_i will be selected for regeneration is given by equation 4.7 above.

We go further to calculate the probability that a schema H will be passed on to a child string as follows:

Step 1- Selection:

The probability **P** that a string is selected which contains the bit pattern H is:

$$P = \frac{f(H_1)}{Nf_\mu} + \frac{f(H_2)}{Nf_\mu} + \ldots\ldots + \frac{f(H_k)}{Nf_\mu} \qquad 4.8$$

Where $H_1, H_2, \ldots, H_k$ represents all strings of the generation which contain the bit pattern *H*. if there are no such strings, the $P = 0$.

$$PNf_\mu = f(H_1) + f(H_2) \ldots\ldots + f(H_k)$$

The fitness *f*(*H*) of the bit pattern *H* in the generation *t* is defined as

$$f(H) = \frac{f(H_1) + f(H_2) + \ldots\ldots + f(H_k)}{n(H, t)} \qquad 4.9$$

Remember when you equate n(H,t)f(H) from equ 4.9 with PNf_μ in equ 4.8 we will have equ 4.10

$$P_{select} = \frac{n(H,t)\, f(H)}{Nf_\mu} \qquad 4.10$$

Furthermore, the probability P_A that two strings which contain pattern *H* are selected as parent is given by:

$$P_A = \left(\frac{n(H,t)\, f(H)}{Nf_\mu}\right)^2 \qquad 4.11$$

Therefore, the probability P_B that from two selected strings only one contains the pattern H is:

$$P_B = 2\left[\left(\frac{n(H,t)\, f(H)}{Nf_\mu}\right)\left(1 - \frac{n(H,t)\, f(H)}{Nf_\mu}\right)\right] \qquad 4.12$$

Step 2- Crossover:

For the crossover of two strings a cut-off point is selected between position **1 and *l*-1** before crossover is executed.

The probability ***W*** that a schema ***H*** is transmitted to the new string depends on two cases:

Case 1: If both parent strings contain ***H***, then they pass on this substring to the new string.

Case 2: If only one of the strings contain H, then the schema is inherited at most half the time

From the foregoing, it can be concluded that the probability ***W*** of an offspring inheriting a character trait/substring from the parents is greater than or equal to the probability of both or either parents selected for regeneration having the character trait and the probability that the character trait is not destroyed during crossover.

We also need to find the probability P_D of the substring H, being destroyed during crossover

Now note that $P_D + P_S = 1$ therefore $P_S = 1 - P_D$

The probability of death P_D is equal to the defining length **δ(H)** divided by the length of the string

$$P_D = \frac{\delta(H)}{l - 1}$$

Our work is interested in survival and not death hence equ 4.13

Therefore the probability of survival is $P_S = 1 - P_D$

Therefore

$$P_S = 1 - \frac{\delta(H)}{l - 1} \qquad 4.13$$

This implies that our W will be:

$$W \geq \left(\left(\frac{n(H,t)\, f(H)}{Nf_\mu} \right)^2 + 2 \left(\left(\frac{n(H,t)\, f(H)}{Nf_\mu} \right) \left(1 - \frac{n(H,t)\, f(H)}{Nf_\mu} \right) \right) \right) \left(1 - \frac{\delta(H)}{l - 1} \right) \qquad 4.14$$

Simplifying further we have:

$$W \geq \left(\frac{n(H,t)\, f(H)}{Nf_\mu} \right) \left(2 - \frac{n(H,t)\, f(H)}{Nf_\mu} \right) \left(1 - \frac{\delta(H)}{l - 1} \right) \qquad 4.15$$

Step 3 - Mutation:

For our probability to be correct we must consider mutation. Mutation causes a change in one of the bit. If it does happen it means that one of the bit will change and it will move from that schema. The effect is that it will not give the required pattern that is needed, because it neither belongs to the father nor mother.

Note

Prob of Mutation + Prob of Non mutation = 1

Therefore Prob of non mutation = 1 – Prob of mutation

We are concern with the probability of non mutation because we don't want the bit to change and we don't want death.

Recall from equ 4.15

$$W \geq \left(\frac{n(H,t)\, f(H)}{Nf_\mu} \right) \left(2 - \frac{n(H,t)\, f(H)}{Nf_\mu} \right) \left(1 - \frac{\delta(H)}{l - 1} \right)$$

Therefore multiplying by non mutation gives equ 4.16

$$W' \geq \left(\left(\frac{n(H,t)\, f(H)}{N f_{\mu}} \right) \left(2 - \frac{n(H,t)\, f(H)}{N f_{\mu}} \right) \left(1 - \frac{\delta(H)}{l - 1} \right) \right) (1 - P_M)^{o(H)} \quad 4.16$$

When two strings are recombined, the information contained in them is copied bit by bit to the child string. A mutation produces a bit flip with the probability P_M. This implies that a schema *H* with *o(H)* fixed bits will be preserved after copying the probability $(1-P_M)^{o(H)}$. If mutation does not occurs, then the probability *W*, of the schema *H* being passed on to a child string changes to W' as seen in equ 4.16

If in each generation *N* new strings are produced, the expected value of the number of strings which contain *H* in the generation *t+1* is NW':

$$n(H,t+1) \geq \frac{n(H,t)\, f(H)}{N f_{\mu}} \left(2 - \frac{n(H,t)\, f(H)}{N f_{\mu}} \right) \left(1 - \frac{\delta(H)}{l - 1} \right) \quad 4.17$$

Equ 4.16 tells us the chances of survival after selection

This means that the number of the child string containing the schema *H* after mutation is greater than or equal to the probability of the schema *H* being passed on to the child string after mutation.

Now, we substitute the value of W' into equation 4.3:

Recall equation 4.3 is:

P(GA) = W'

Therefore, substituting equation 4.15 into equation 4.3 we have:

$$P(GA) \geq \frac{n(H,t)\, f(H)}{N f_{\mu}} \left(2 - \frac{n(H,t)\, f(H)}{N f_{\mu}} \right) \left(1 - \frac{\delta(H)}{l - 1} \right) (1 - P_M)^{o(H)} \quad 4.17$$

4.7 Input/Output Specification

The input for this Tv white space optimization performance is gotten immediately the users access the select the transmitter location. Here the input specification is structured to scan the locations under consideration and allocate any free channel that has met the knowledge base conditions to a requesting WSD. The system simulates the real world scenario and generates random number for the requesting WSD, the free channels are allocated to the random numbers in an odd and even format putting into consideration primary user presence and interference. All the information about the frequencies in different locations is recorded in the database. The locations considered in this work are Asaba and environs, Awka and environs, Nkpor and environs and Ubulu-Uku and environs as analyzed in section 3.5. Theses analysis of the channel availability was also used as part of input specification.

The users of the TV white space optimization gets access to the system through a login module as shown in figure 4.11

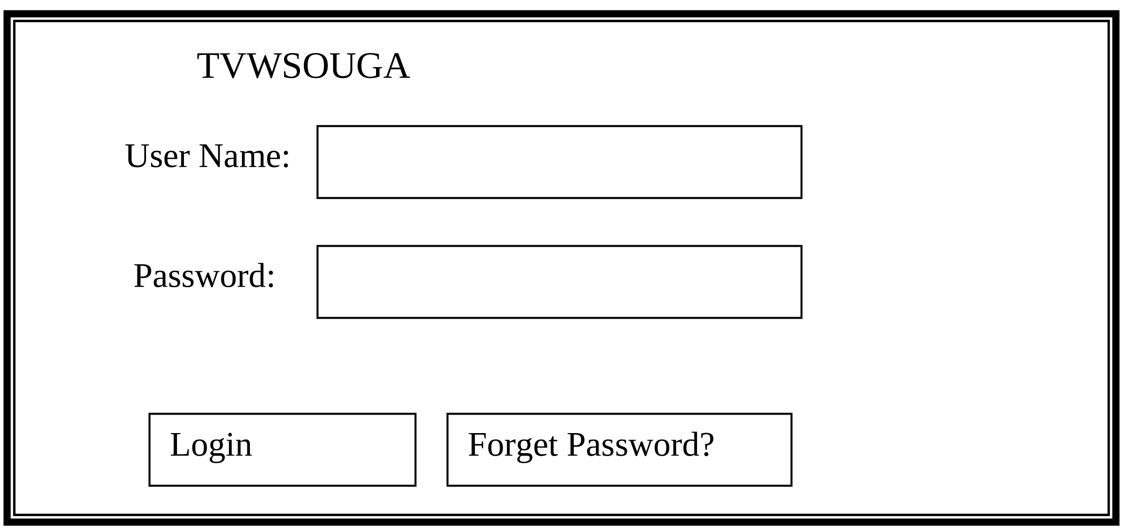


Figure 4.11: Login Module with User name and Password

Figure 4.12 below allows you to know if there are channels available, if there are you proceed if not you click on refresh.

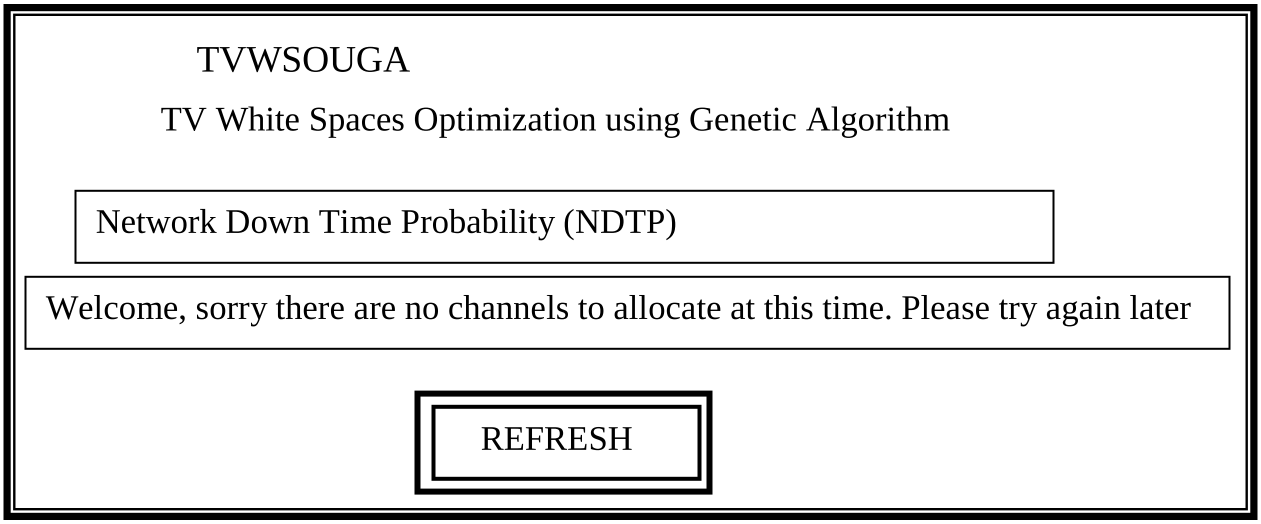


Figure 4.12: Network Unavailability dialog Box

If there are channels available to allocate at the time of request figure 4.13 allow you to proceed to the main programme for allocation to take place.

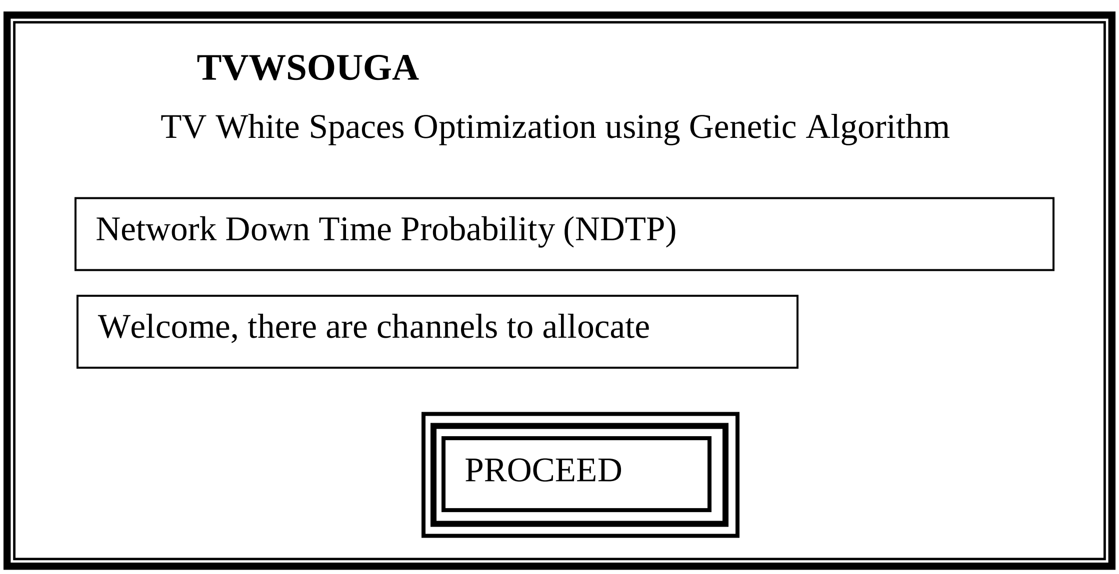


Figure 4.13: Network Availability dialog Box

The initial input format at start up of the TV White space optimization from figure 3.9 is illustrated in table 4.8

Table 4.8: Input Sample from TV Optimization in Awka Location

S/N	Band	Channel No	Status
1	474 – 482MHz	21	Occupied
2	482 – 490MHz	22	Occupied
3	490 – 498MHz	23	Free
4	498 – 506MHz	24	Free
5	506 – 514MHz	25	Free
6	514 – 522MHz	26	Free
7	522 – 530MHz	27	Free
8	530 – 538MHz	28	Free
9	538 – 546MHz	29	Free
10	546 – 554MHz	30	Free
TOTAL INPUT			10

Output Specification

The new system is designed to allow the maximum use of available TV white spaces opportunistically by the secondary unlicensed users. The gelocation technique was adopted which senses the available TV white spaces and allocate device to them for broadcasting with optimum exchange of information via the database. It monitors all possible interference occurrence situations and avoids them. The frequencies within a particularly geolocation is sensed to determine its status. The table below shows the sense result in different locations.

Table 4.9: Sample of Output format of the Channel Allocation from TV Optimization in Awka Location.

S/N	Band	Channel No	Status
1	474 – 482MHz	21	No_Action
2	482 – 490MHz	22	Do_Not_Allocate
3	490 – 498MHz	23	No_Action
4	498 – 506MHz	24	Do_Not_Allocate
5	506 – 514MHz	25	No_Action
6	514 – 522MHz	26	Allocate
7	522 – 530MHz	27	No_Action
8	530 – 538MHz	28	Allocate
9	538 – 546MHz	29	No_Action
10	546 – 554MHz	30	Allocate

Table 4.10: Sample of Output format of the Channel Allocation from TV Optimization in Ubulu-Uku Location.

S/N	Band	Channel No	Status
1	474 – 482MHz	21	Do_Not_Allocate
2	482 – 490MHz	22	No_Action
3	490 – 498MHz	23	Do_Not_Allocate
4	498 – 506MHz	24	No_Action
5	506 – 514MHz	25	Do_Not_Allocate
6	514 – 522MHz	26	No_Action
7	522 – 530MHz	27	Allocate
8	530 – 538MHz	28	No_Action

9	538 – 546MHz	29	Allocate
10	546 – 554MHz	30	No_Action

4.7.1 Algorithm

Algorithms are patterns or procedures for completing a task in an efficient way. Algorithm can also be defined as Step by step procedure designed to perform an operation which you will take in order to reach a specific goal.

Step 1 Start the server and enable it to accept inputs, type localhost at the browser address bar then login with your user name and password,

Step2 Ensure that the frequency are available if not click refresh on the dialog box,

Step3 Choose the transmitter location depending on the location you want to allocate WSD,

Step 4 Refresh the page for allocation to take place,

Step 5 Check to see that allocations are successful,

Step 6 If step 4 is successfully done, the allocation table will start receiving requests from the WSD,

Step 7 Behind the scene the genetic optimization algorithm selects the best channels that meets the inference rule and allocate WSD based on the random number generated,

Step 8 Channels that free but close to the occupied are not allocated to avoid interference and

Step 9 Click on GA console to view other transmitter locations and repeat step 2 to step 7.

4.7.2 Data Dictionary

A data dictionary, or data repository, is a central storehouse of information about the system's data. The main purpose of a data dictionary is to describe, document and organize facts about the system and the database. The data dictionary for the system is illustrated in table 4.11

Table 4.11: The Data Dictionary for the TvWSOUGA System

S/N	VARIABLE	DESCRIPTION
1	jta	A Java Swing Text Area Component. This component is used to display the out put of the genetic algorithm,ga, object.
2	jbtn	A Java Swing Button Component used to refresh the genetic algorithm object.
3	jbtnclose	A Java Swing Button Component used to clear the text display area.
4	BEGIN	A primitive variable of type long used to flag the beginning of execution of the genetic algorithm object.
5	population	A linked list object of the Candidate class. It is used to hold a list of Candidate Objects that form our genetic algorithm population.
6	jsp	A Java Swing Scroll Pane used to add scrolling effects and scroll bars to the jta JTextArea object.
7	ap	AnalysisPanel object used to display current location.
8	P1	A Java Swing Panel Object used to hold the jsp and p2 objects in the application display window.
9	p2	A Java Swing Panel object used to hold jbtn and the jbtnclose objects in the application display window.
10	plot	A SineFrame object used to plot and display the amplitude of the frequency
11	p4	A Java Swing Panel object used to hold and display the SineFrame object, plot in the application
12	scanner	A RadarPane object used to display the signal scanner.
13	model	A LoadJTableData Abstract Table Model object used to populate the table object.
14	table	A JTable object used to hold and display tabular information retrieved from the database.

S/N	VARIABLE	DESCRIPTION
15	p3	A JPanel object used to hold the panel object that contains our tabular data.
16	panel	A JPanel object used hold the table object.
17	C1,c2,c3,c4,w1,w2,child1,child2	Objects of the Candidate Class used to generate next generations viable bit strings or genes.
18	Childs	An array of Candidate class that contains children/ Childs generated in the next generation.
19	f1,f2, f3 and f4	Fitness of c1,c2,c3 and c4 respectively.
20	m1 and m2	Boolean flags used to determine whether to mutate child1 or child2
21	isChild1Good,	Boolean flag used determine if the fitness of child1 is higher than the fitness of any other arbitrary child, say w1, taken from the population sample for comparison.
22	isChild2Good	Boolean flag used determine if the fitness of child2 is higher than the fitness of any other arbitrary child, say w2, taken from the population sample for comparison.
23	ga	An object Genetic Algorithm class that holds and displays all the applications processing and output.
24	maxStep	A constant that holds the number of times selection, crossover and mutation will take place in a given population and produce the next generation until the generation.
25	count	An integer counter variable used to count the number of times selection, crossover, mutation and production of the next generation has occurred.
26	print()	This a method of the GA class used to display output
27	run()	A method of the GA class used call an object of the GA class to action.
28	ProduceNextGeneration()	Is a method of the GA class used by ga object to select, crossover, mutate and generate next generation of genes with desired fitness.
29	newChild(Candidate c1, Candidate c2)	A method of the GA class used by ga objects to perform crossover
30	Mutate (Candidate c)	This method of the GA class is used to mutate a Candidate gene or solution.
31	main(String[] args)	The main method of the GA class is used to instantiate a ga object and invoke its run() method.
32	GA()	Constructor of the GA class

S/N	VARIABLE	DESCRIPTION
33	Candidate()	Constructor of the Candidate class.
34	random()	The random() method of the Candidate class is used to generate/ assign random genotype.
35	gene()	The gene method of the Candidate Class is used build binary genes
36	fitness()	As the name suggests, the fitness() method of the Candidate class is used to calculate the fitness of each gene in the population for selection
37	compareTo()	This method is used to compare the fitness of two Candidate objects for best fit. It returns 1 if the current Candidate' fitness is less than fitness of the supplied Candidate, -1 if the fitness of the current Candidate is greater than the fitness of the supplied Candidate and 0 is equal.
38	toString()	This method of the Candidate class is used to display binary gene and the gene's fitness . It returns a String

Table 4.12: The Data Dictionary for the TVWSOUGA Database

S/N	FIELD NAMES	FIELD TYPES	FIELD SIZE	CONSTRAINT	DESCRIPTION
1	ID	Number		Primary Key	Serial number of rules
2	Rule_id	VARCHAR	10	Not Null	A unique id given to a rule
3	Clause_id	VARCHAR	10	Foreign key Referenced	Used to reference foreign keys
4	conjunction	Enum(‘AND’,’OR’,’IMPLICATION’)	10	Not Null	Used to combine clauses in a rule
6	Rule_variableid	VARCHAR	10	Primary Key	This is part of the clause used in the inference rule
7	condition	Enum(‘AND’,’OR’,’IMPLICATION’)	10	Not Null	This is used to describe the conditions in the inference engine

S/N	FIELD NAMES	FIELD TYPES	FIELD SIZE	CONSTRAINT	DESCRIPTION
8	Clause_type	Enum('ANTECEDENT','CONSEQUENT')	10	Not Null	This is part of the rules in the inference engine eg channel 25 is adjacent to channel 24
9	Clause_value	VARCHAR	20	Not Null	This also part of the clause used in the inference rule
10	Freq_band	VARCHAR	7	Not Null	This is used to represent the frequency band
11	Location	VARCHAR	5	Not Null	This is used to describe the channel location
12	CR_id	VARCHAR	6	Not Null	This is used to describe the CR identification location
13	DBC	Enum('0','1')	ENUM	Not Null	This is used to describe the Database Channel
14	PIB	Enum('0','1')	ENUM	Not Null	This is the Power in Band
15	POOB	Enum('0','1')	ENUM	Not Null	This is the Power out of Band
16	CNR	Enum('0','1')	ENUM	Not Null	This is used to describe the Carrier Noise Ratio
17	PR	Enum('0','1')	ENUM	Not Null	This used to describe the protection ratio
18	EL	Enum('0','1')	ENUM	Not Null	This is used to describe the Emission Limit of the transmitter
18	DBSS	Enum('0','1')	ENUM	Not Null	This used to describe the Database Subscriber Station
19	CRUE	Enum('0','1')	ENUM	Not Null	This is the Cognitive Radio user Equipment

S/N	FIELD NAMES	FIELD TYPES	FIELD SIZE	CONSTRAINT	DESCRIPTION
20	CRLocation	Enum(‘0’,’1’)	ENUM	Not Null	This stores the cognitive location
21	Adjacent_CR	Enum(‘0’,’1’)	ENUM	Not Null	This stores the CR that is near to the CR we are considering for allocation
22	Adjacent_CR_Directi	Enum(‘N’ ‘W’ ‘E’ ‘NE’‘NW’ ‘SE’ ‘SW’	ENUM	Not Null	This sores the direction of adjacent CR

4.8 System Flow Diagram

The new system flow diagram is shown in figure 4.12. Here, the system consists of two sections, the rule base system and the genetic algorithm system. Rule based is applied because of uncertainty or imperfection or incomplete information that might occur in the real world scenario why genetic algorithm will help in the reduction of execution time and also improve resource utilization rate and allocation at any time.

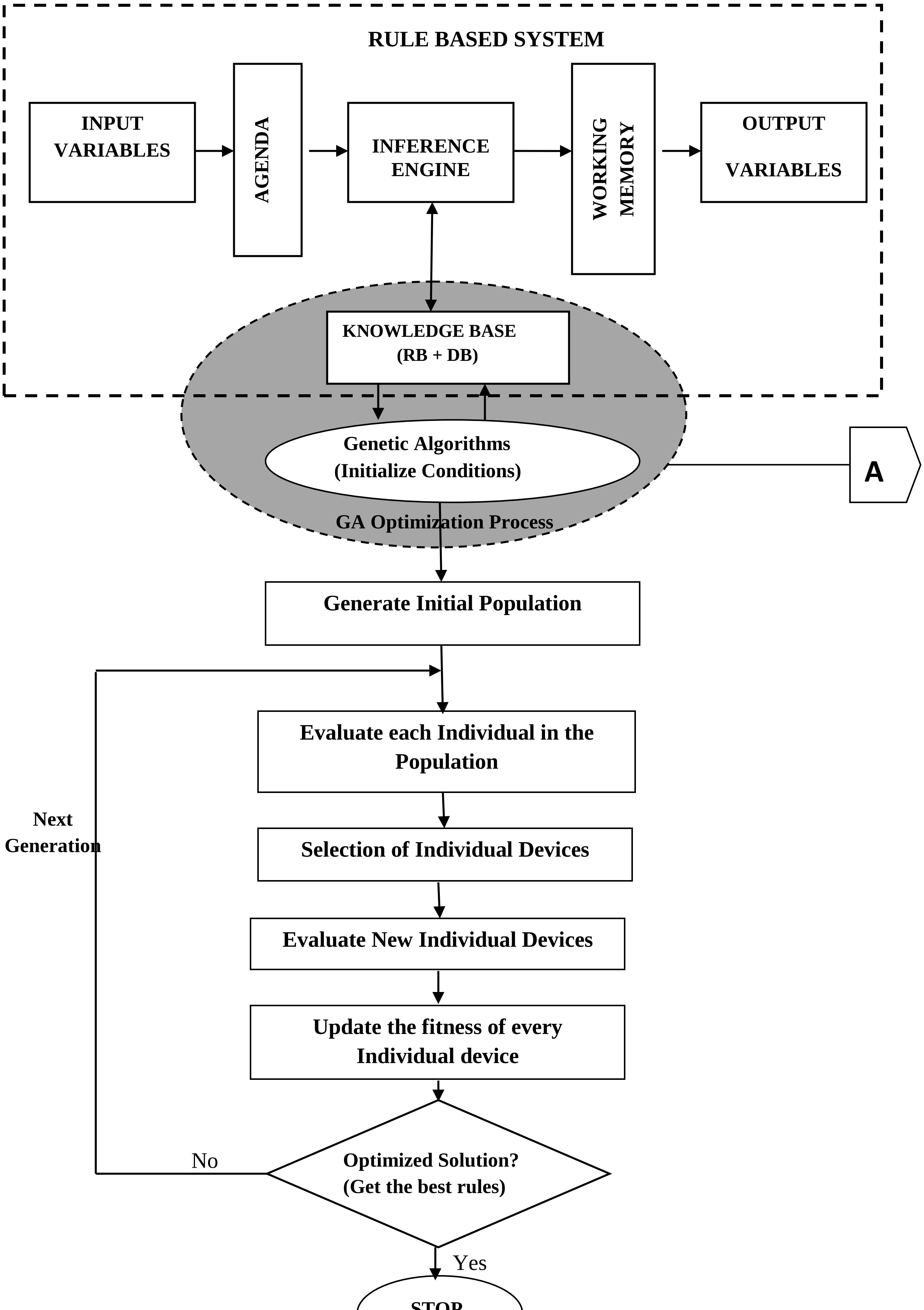
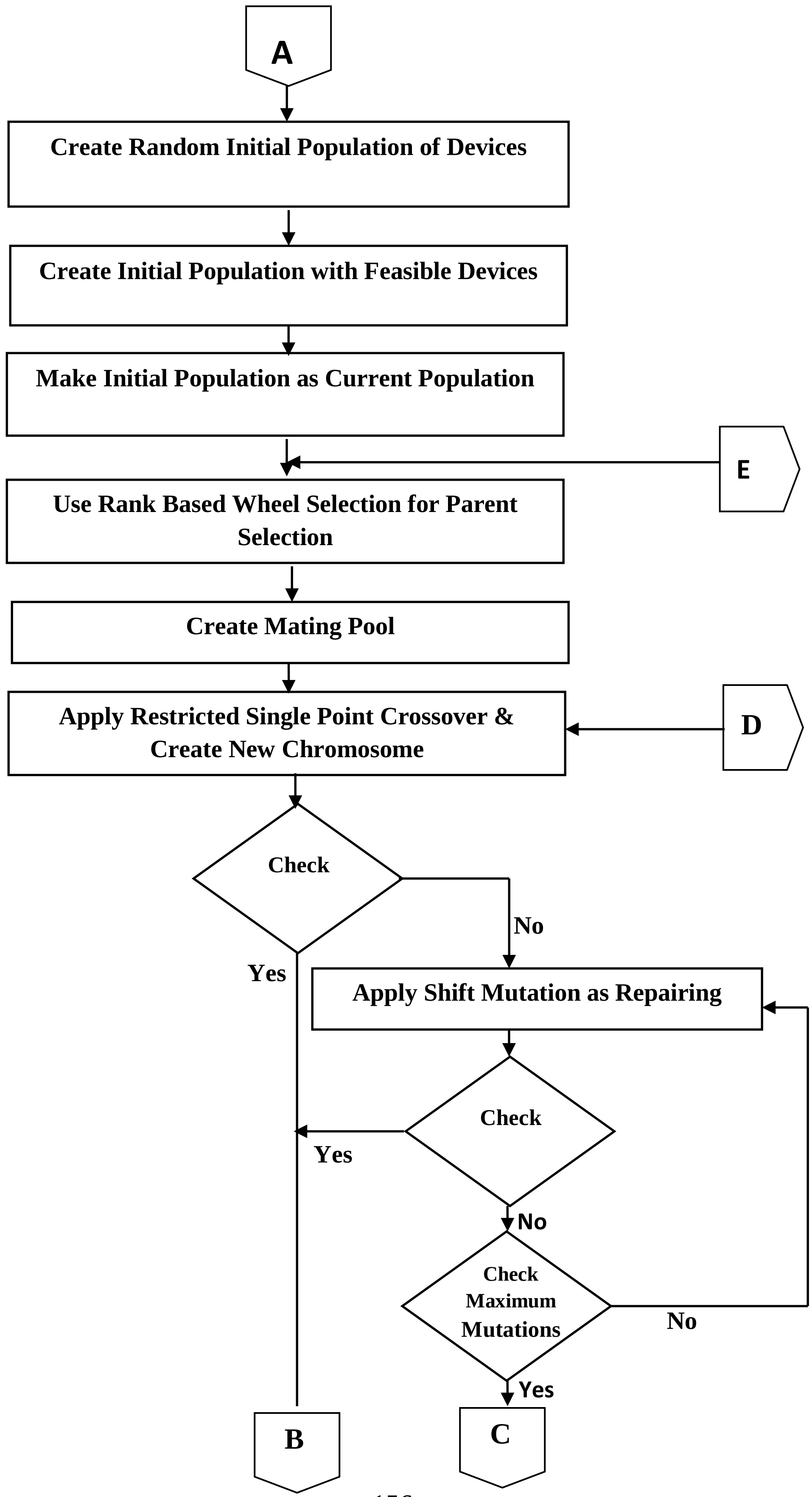


Figure 4.14: Proposed Rule based and Genetic Algorithm Flow Diagram


A
Create Random Initial Population of Devices
Create Initial Population with Feasible Devices
Make Initial Population as Current Population
E
Use Rank Based Wheel Selection for Parent Selection
Create Mating Pool
Apply Restricted Single Point Crossover & Create New Chromosome
D
Check
No
Yes
Apply Shift Mutation as Repairing
Check
Yes
No
Check Maximum Mutations
No
Yes
B
C

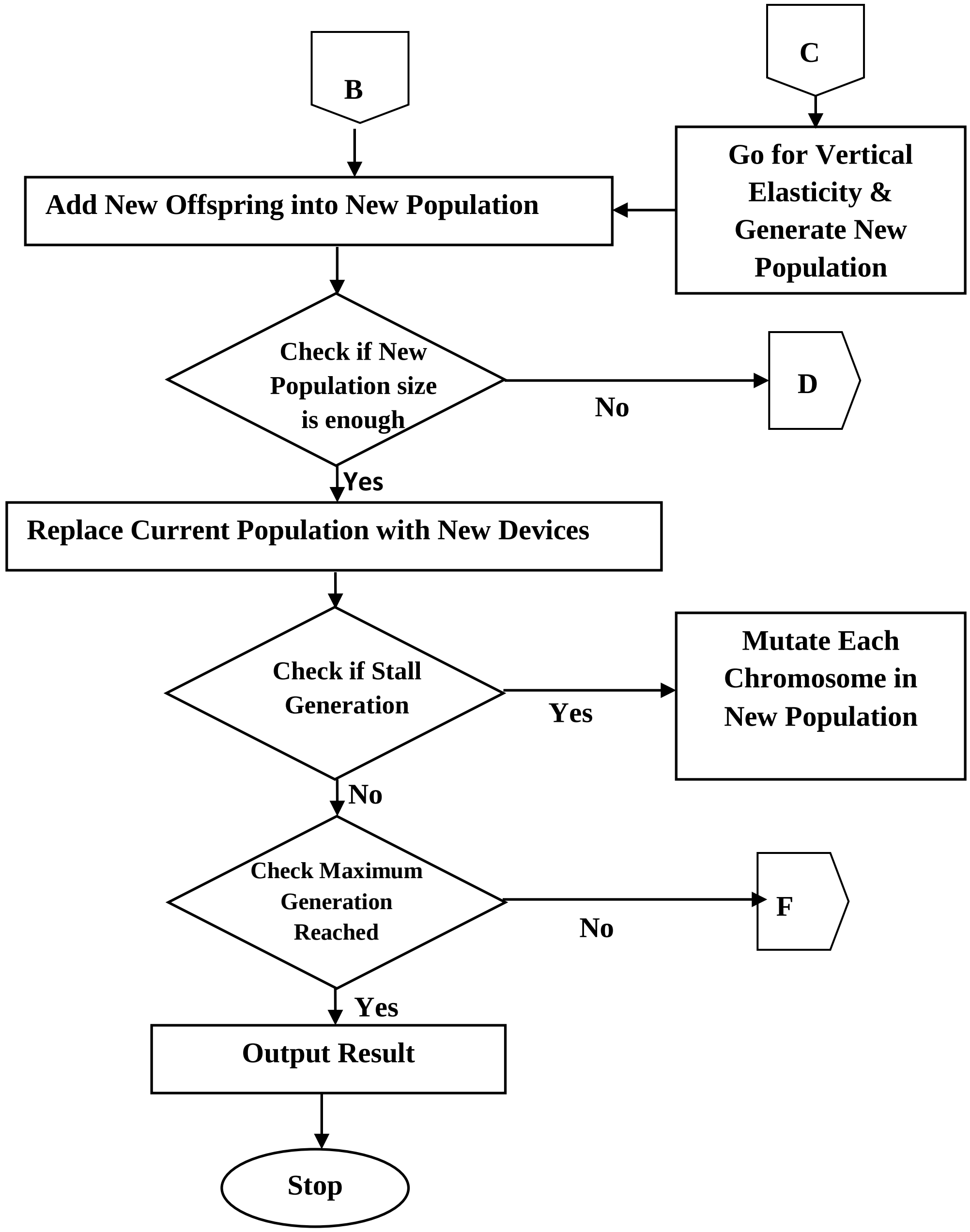


Figure 4.15: Workflow of proposed Algorithm

4.9 System Implementation

System implementation is a very important stage in software development, it uses the structure created during architectural design and the results of system analysis to construct system elements that meet the stakeholder requirements and system requirements developed in the early life cycle phases. In this research work different requirements are stated for flawless implementation of the work.

4.9.1 Proposed System Requirements

Computer software needs certain hardware components or other software resources to be present in other to work efficiently. These prerequisites are known as the system requirements and are often used as a guideline as opposed to an absolute rule. The system requirements is defined by two sets of minimum and recommended. In order hand, system implementation tries to explain the method of implementing and storing the programs for future use. Also important in this stage is the method of changing from the old system to the new system without having serious effect on the organization.

4.9.2 Hardware Requirements

A hardware requirements list is often accompanied by a hardware compatibility list (HCL), especially in case of operating systems. HCL lists are tested, compatible, and sometimes incompatible hardware devices for a particular operating system or application. The hardware requirement is classified as follows

Table 4.13: Basic Hardware Required

Hardware components	**Minimum Requirement**	**Recommended**
Processing power	CPU with SSE2 support, including Intel Pentium 4, Pentium M, Core or Atom, AMD Athlon 64 or later	A core i3 processor with processing speed of 1.2GHz or higher

Memory	1 GB or more	3 GB or more
Secondary storage	5GB of free space	10 GB of Free Space
Display adapter	NVIDIA GeForce 6600 or better **OR** ATI Radeon 9500 or better **OR** Intel 945 chipset	*NVIDIA Graphics cards* 9000 Series: 9600, 9800 200 Series: OR 275 GTX, 295 GTX *ATI Graphics Cards* 4000 Series:
Screen Resolution	800 X 1024 pixels	1366 X 768 pixels or higher
Sound Card	Direct X9.0 compatible sound card	Direct x10 Compatible Sound card

4.9.3 Software Requirements

Software requirement deals with defining software resource requirements and prerequisites that need to be installed on a computer to provide optimal functioning for an application. These requirements or prerequisites are generally not included in the software installation package and need to be installed separately before the software is installed.

Table 4.14: Software Required

Hardware components	**Minimum Requirement**	**Recommended**
APIs and drivers	Apache Derby Driver	Apache Derby Driver
Platform	Java Run Time Environment (JRE) release 8	Java Run Time Environment (JRE) release 8 or later version
Operating System	Vista, Windows XP, Windows 7, Windows 8	Vista, Windows XP, Windows 7, Windows 8 or

	or Windows 10, Mac OS X 10.7 or better, or a 32 or 64 bit Linux environment	Windows 10, Mac OS X 10.7 or better, or a 32 or 64 bit Linux environment

4.10 Program Development

This is the process taken in developing the software for the new system. There were several processes taken into consideration in order to achieve the software that will meet the specification for the new system.

4.10.1 Choice of Programming Language

The Programming language use include the following

i) HTML: This is a mark-up language it was used in this work in creating forms and objects that were used in carrying out the task in the development of the new system.

ii) Cascading Style Sheet (CSS): This was use to create styles in the design of the application to make the interface more appealing to the user of the new system.

iii) PhpMyAdmin: This was to enable access to the database.

iv) JavaScript was use in creating some transitions and also to make movement of objects possible like the 3D chart.

v) Hypertext Preprocessor (PHP) was employed in the development of the backend of the new system. PHP created a communication access between the system and the database. The action processes in this work was made possible because of the PHP.

vi) Apache was used as a server that enable the new system run a PHP software on a PC without the requirement of an Internet connection.

4.10.2 Language Justification

Due to the web application of this research the above languages were used in order to achieve the demand in the specification of this work. The followings are some of the parameters that influence the choice of the programming language used

HTML is a globally accepted programming language for formatting web pages. In today's world, it is commonly used along with JavaScript and Cascading Style Sheets (CSS) to give web pages the look and feel we desire. Through HTML, the look and appearance of images, links, headings, text, page layout and just about every element of a web page can be formatted. It is also the most optimal for most small and growing businesses that do not really need advanced functionality on their website. Below are some of the advantages of using HTML while creating your website.

PHP is a server side scripting language that is used to develop Static websites or Dynamic websites or Web applications. PHP is known for its ability to optimize memory. As a result, it never allows server overloading. Instead, it helps in improving a server's processing speed significantly. The following were the reasons for chosen PHP in this work:

i) **Easy to Manage:** PHP comes with a normal setting of 1-1 correspondence between files and URLs. This is a great advantage as it helps users (programmers, designers and others) in creating pages and making edits. This feature comes in handy while working on static websites which have a large base of content in it. Making subtle changes to such pages would otherwise require a good deal of over-engineering, but with a PHP framework it becomes easier.

ii) **Easy to Scale:** PHP is easier to scale which makes it all the more transparent to use. Those looking to understand the minutest of details of a code can get a better understanding of it with PHP. Those programming in a much complex framework than PHP would have to make their way through the nitty-gritty's of various classes and subclasses to actually understand how exactly the code is working. Hence using PHP makes it easier to follow and save time as well.

iii) **More Reliable:** What makes PHP a more reliable framework to work on is a separated isolate process within 'Apache'. Hence even if there is some glitch in any one of the processes, the website would still remain virtually unaffected.

iv) **Runs on All Platforms:** A PHP web development makes a website run on all leading platforms such as Windows, MAC OS, UNIX and Linux.

v) **Proven Security:** PHP has numerous layers of security which keeps malicious attacks and threats at bay.

Another prominent advantage of using this language is that it can be embedded into HTML without any difficulty. Integrating the language with advanced visual applications such as Ajax and Flash also involves some very simple steps.

This work also used Cascading Style Sheets or CSS because of its way to control how your Web pages look. CSS can control the fonts, text, colors, backgrounds, margins, and layout. CSS gives you the opportunity to create sites that look very different from page to page, without a lot of extensive coding. The following characteristics of CSS motivated us in choosing it for this work:

Consistency: By making one change to your website's CSS style sheet, you can automatically make it to every page of your website. The bigger your website, the more time CSS saves you. And not only does CSS save time, it also ensures that your web pages have consistent styling throughout your site.

Bandwidth Reduction: When CSS separates your website's content from its design language, you dramatically reduce your file transfer size. Your CSS document will be stored externally, and will be accessed only once when a visitor requests your website. In contrast, when you create a website using tables, every page of your website will be accessed with each visit. Your reduced bandwidth needs will result in a faster load time and could cut your web hosting costs.

Search Engines: CSS is considered a clean coding technique, which means search engines won't have to struggle to read its content. Also, using CSS will leave your website with more content than code – and content is critical to your search engine success.

Browser Compatibility: The recent arrival of Google Chrome is further evidence that today's Internet users have more browser options than ever before, which makes browser compatibility a major issue for your website. CSS style sheets increase your website's adaptability and ensure that more visitors will be able to view your website in the way you intended.

Viewing Options: Another common web design concern is the increasing need to make websites available for different media. CSS can help you tackle this challenge by allowing the same markup page to be presented in different viewing styles.

4.11 System Testing

The new TV white space optimization system was tested in a simulated environment against already existing system and the result shown. The main reason for using a simulated environment is because of the cost of real implementation and the nature of the environment in a real life situation.

4.11.1 Test Plan

The test plan include

i) First verify that the available table in all the locations are working and that the frequency scanning process using is functioning

ii) Verify your login process to ensure that the password is functioning

iii) Testing the interference situation using the free channels in the test data as seen in table 4.15, 4.16, 4.17 and 4.18 to ensure that channels free channels close to primary user channels are not assigned to white space device irrespective of demand.
iv) Testing the channel optimization using the data in tables 4.15, 4.16, 4.17 and 4.18 for different locations and monitor allocation performance
v) Check for any conflict in the allocation using the simulated random numbers and also channel fitness.

4.11.2 Test Data

The test data used was gotten from the channel availability analysis made in different locations as well as the received signal strength in each location. In each of the locations free channel fitness were computed and upon request by white space devices the free channels were allocated with consideration of the primary users thereby reducing interference to its beeriest minimum.

Table 4.15: Test Data for TV white space optimization in Awka Location

Frequency span	**Channel No**	**Status**	**Results**
474 – 482MHz	21	Occupied/in use	No_ Action
482 – 490MHz	22	Occupied/in use	Do_Not_Allocate
490 – 498MHz	23	Free	No_ Action
498 – 506MHz	24	Occupied/in use	Do_Not_Allocate
506 – 514MHz	25	Free	No_ Action
514 – 522MHz	26	Free	Allocate
522 – 530MHz	27	Free	No_ Action
530 – 538MHz	28	Free	Allocate
538 – 546MHz	29	Free	No_ Action

546 – 554MHz	30	Free	Allocate
554 – 562MHz	31	Free	No_ Action
562 – 570MHz	32	free	Allocate
570 – 578MHz	33	Free	No_ Action

Table 4.16: Test Data for TV white space optimization in Awka Location

Frequency span	Channel No	Status	Results
474 – 482MHz	21	Occupied/in use	Do_Not_Allocate
482 – 490MHz	22	Occupied/in use	No_ Action
490 – 498MHz	23	Free	Do_Not_Allocate
498 – 506MHz	24	Occupied/in use	No_ Action
506 – 514MHz	25	Free	Do_Not_Allocate
514 – 522MHz	26	Free	No_ Action
522 – 530MHz	27	Free	Allocate
530 – 538MHz	28	Free	No_ Action
538 – 546MHz	29	Free	Allocate
546 – 554MHz	30	Free	No_ Action
554 – 562MHz	31	Free	Allocate
562 – 570MHz	32	free	No_ Action
570 – 578MHz	33	Free	Allocate

From table 4.15 and 4.16, we have the available channels that can be allocated to WSDs, the interference condition was tested using channel 23 and 25 in either cases in both tables the results shows that WSDs were not assigned to this channels due to closeness to the primary users. The allocations were successful in both tables using our simulated odd and even number generation. The same is also applicable in table 4.17 and 4.18 for Nkpor location, the interference condition was tested using channels 23, 25, 31 and 33 the results shows that though these channels were free but are not fit for allocation because of their closeness to primary users.

Table 4.17: Test Data for TV white space optimization in Nkpor Location

Frequency span	**Channel No**	**Status**	**Results**
474 – 482MHz	21	Free	No_ Action
482 – 490MHz	22	Free	Allocate
490 – 498MHz	23	Free	No_ Action
498 – 506MHz	24	Occupied/in use	Do_Not_Allocate
506 – 514MHz	25	Free	No_ Action
514 – 522MHz	26	Free	Allocate
522 – 530MHz	27	Free	No_ Action
530 – 538MHz	28	Free	Allocate
538 – 546MHz	29	Free	No_ Action
546 – 554MHz	30	Free	Allocate
554 – 562MHz	31	Free	No_ Action
562 – 570MHz	32	Occupied/ in use	Do_Not_Allocate
570 – 578MHz	33	Free	No_ Action

Table 4.18: Test Data for TV white space optimization in Nkpor Location

Frequency span	**Channel No**	**Status**	**Results**
474 – 482MHz	21	Free	Allocate
482 – 490MHz	22	Free	No_ Action

490 – 498MHz	23	Free	Do_Not_Allocate
498 – 506MHz	24	Occupied/in use	No_ Action
506 – 514MHz	25	Free	Do_Not_Allocate
514 – 522MHz	26	Free	No_ Action
522 – 530MHz	27	Free	Allocate
530 – 538MHz	28	Free	No_ Action
538 – 546MHz	29	Free	Allocate
546 – 554MHz	30	Free	No_ Action
554 – 562MHz	31	Free	Do_Not_Allocate
562 – 570MHz	32	Occupied/ in use	No_ Action
570 – 578MHz	33	Free	Do_Not_Allocate

Table 4.19: Test Data for TV white space optimization in Ubulu-Uku Location

Frequency span	**Channel No**	**Status**	**Results**
474 – 482MHz	21	Occupied/in use	Do_Not_Allocate
482 – 490MHz	22	Occupied/in use	No_ Action
490 – 498MHz	23	Occupied/in use	Do_Not_Allocate
498 – 506MHz	24	Occupied/in use	No_ Action
506 – 514MHz	25	Free	Do_Not_Allocate
514 – 522MHz	26	Free	No_ Action
522 – 530MHz	27	Free	Allocate
530 – 538MHz	28	Free	No_ Action
538 – 546MHz	29	Free	Allocate
546 – 554MHz	30	Free	No_ Action

554 – 562MHz	31	Occupied/in use	Do_Not_Allocate
562 – 570MHz	32	Occupied/in use	No_ Action
570 – 578MHz	33	Occupied/in use	Do_Not_Allocate

Table 4.20: Test Data for TV white space optimization in Ubulu-Uku Location

Frequency span	**Channel No**	**Status**	**Results**
474 – 482MHz	21	Occupied/in use	No_ Action
482 – 490MHz	22	Occupied/in use	Do_Not_Allocate
490 – 498MHz	23	Occupied/in use	No_ Action
498 – 506MHz	24	Occupied/in use	Do_Not_Allocate
506 – 514MHz	25	Free	No_ Action
514 – 522MHz	26	Free	Allocate
522 – 530MHz	27	Free	No_ Action
530 – 538MHz	28	Free	Allocate
538 – 546MHz	29	Free	No_ Action
546 – 554MHz	30	Free	Do_Not_Allocate
554 – 562MHz	31	Occupied/in use	No_ Action
562 – 570MHz	32	Occupied/in use	Do_Not_Allocate
570 – 578MHz	33	Occupied/in use	No_ Action

In table 4.19 and 4.20, interference condition was also tested using Ubulu-Uku location. Using channel 25 and 30 as a case study in this table, allocation was not made, though these channels were free but close to primary user. In every other situation allocations were made to channels with best fitness.

4.11.3 Testing the Optimization Model

The optimization model used in section 4.6 was tested to determine its validity using different randomly generated strings of different length. A schema of ****10*1** was used as shown in table 4.21. A crossover was performed selecting two different parents at a cross site of 5 as shown in tables 4.22 and 4.23 respectively

Table 4.21: Schema of length 10 and three fixed positions

N	Population (generated randomly)	Code	Fitness F(H)	P(select)	Expected Count
1	1101101100	876	767376	2.17	2
2	0101100101	357	127449	0.36	0
3	1000101101	557	310249	0.88	1
4	0011100110	230	52900	0.15	0
5	0000101111	47	2209	0.0063	0
6	1110100111	935	874225	2.48	3
7	1010100100	676	456976	1.29	1
8	0111100100	484	234256	0.66	1
	Total fitness		**2825640**		
	Average		**353205**		

Table 4.22: Parents 6 and 1 selected

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
6	11101| 00111	1110101100	940	883600	874225
1	11011| 01100	1101100111	871	758641	767376
			Total	**1642241**	**1641601**

Table 4.23: Parents 7 and 3 selected

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
7	10101| 00100	1010101101	685	469225	456976
3	10001| 01101	1000100100	871	300304	310249
			Total	**769529**	**767225**

Another random string of numbers were also generated with a schema **10****** as shown in table 4.24.

Table 4.24: A schema with two fixed positions

N	Population (generated randomly)	Code	Fitness F(H)	P(select)	Expected Count
1	1110101011	939	881721	2.35	2
2	0110111000	440	193600	0.52	1
3	0110101010	426	181476	0.48	0
4	1010110011	691	477481	1.27	1
5	0010111111	191	36481	0.1	0
6	0010100111	167	27889	0.07	0
7	1010111100	700	490000	1.31	1
8	1110001111	911	829921	2.21	2
9	1010110110	694	481636	1.28	1
10	0110000110	390	152100	0.41	0
	Total fitness		**3752305**		
	Average		**375230.5**		

A crossover was performed selecting two different parents at a cross site of 5 as shown in tables 4.25 and 4.27 respectively.

Table 4.25: Parents 1 and 9 selected

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
1	11101|01011	1110110110	950	902500	881721
9	10101|10110	1010101011	683	466489	481636
			Total	**1368989**	**1363357**

Table 4.26: Parents 4 and 7 selected

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
4	10101|10011	1010111100	700	490000	477481
7	10101|11100	1010110011	691	477481	490000
			Total	**967481**	**967481**

Table 4.27: Parents 4 and 7 selected

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
4	101011|0011	1010111100	700	490000	477481
7	101011|1100	1010110011	691	477481	490000
			Total	**967481**	**967481**

At cross site of 4, 5 and 6 there were no significant increase in the fitness as seen in tables 4.26 to 4.27

A test of the equation was also carried out using a schema of high defining length $\delta(H$ as shown in table 4.27. The schema is **1***1****

Table 4.28: A schema with high defining length

N	Population (generated randomly)	Code	Fitness F(H)	P(select)	Expected Count
1	11101010101	1877	3523129	1.83	2
2	11111010101	2005	4020025	2.09	2

3	10110111100	1468	2155024	1.12	1
4	10101111111	1407	1979649	1.03	1
5	01101011010	858	736164	0.38	0
6	00111111111	511	261121	0.14	0
7	10110011101	1437	2064969	1.07	1
8	11100111110	1854	3437316	1.79	2
9	10111110001	1521	2313441	1.21	1
10	00110110111	439	192721	0.10	0
11	01100011111	799	638401	0.33	0
12	10100011110	1310	1716100	0.89	1
	Total fitness		**23038060**		
	Average		**1919838.333**		

Table 4.29: Parents 3 and 7 selected cross site of 5

N	Mating Pool	New generation	New Code	New Fitness	Fitness of old pop
3	10110|111100	10110011101	1437	2155024	2064969
7	10110|011101	10110111100	1468	2064969	2155024
			Total	**4219993**	**4219993**

Table 4.30: Parents 3 and 7 selected cross site of 7

N	Mating Pool	New generation	New Code	Fitness of old pop	New Fitness
3	1011011|1100	10110111101	1469	2064969	2157961
7	1011001|1101	10110011100	1436	2155024	2062096
			Total	**4219933**	**4220057**

Table 4.31: Parents 3 and 7 selected cross site of 3

N	Mating Pool	New generation	New Code	Fitness of old pop	New Fitness
3	101|10111100	10110011101	1437	2064969	2155024
7	101|10011101	10110111100	1468	2155024	2064969
			Total	**4219993**	**4219993**

4.11.4 Results

Appendix V shows the results from the TVWSOUGA, in this appendix we have nine different tables showing the available channels from three locations; Awka, Nkpor and Ubulu-uku. These tables were used to show the available channels in each locations, and there after the channels allocations done by the system to the requesting devices as simulated.

In table 4.21 above String 6 and 1 shows an 63% chance of crossing over to produce a better new generation with better fitness with a probability of 0.46 chance of the bits not undergoing mutation While Strings 7 and 3 shows a 59% chance of crossing over to produce a better new generation and fitness with a probability 0.43 chance of the bits not undergoing mutation. When crossed at a site of 5, a stronger new generation was produced with an increase in fitness from 1641601 to 1642241 and 767225 to 769529 respectively. Therefore, the probability of our algorithm being correct is the probability of selection, crossover and mutation.

In table 4.24, string 1 and 9 shows an 86% chance of crossing over to produce a better new generation with better fitness and a probability of 0.70 chance of the bits not undergoing mutation while strings 4 and 7 shows a 77% chance of crossing over to produce a better new generation with better fitness and a probability of 0.62 chance of the bits not undergoing mutation.

In table 4.28 string 3 and 7 was selected and it shows 48% chance of crossing over which is not up to the minimum crossing value, when crossing was eventually applied at different crossing site as shown in table 4.29, 4.30 and 4.31 the result showed no significant change in the fitness.

4.11.5 Discussion

The result of this research work is shown in appendix II, the TVWSOUGA system was able to simulate different locations under consideration and did channel allocation to the requesting white space devices putting into consideration the primary users which was one of the objectives of this work. The result shows that interference was also avoided by the system. The evidence can be seen in our output, channels that were free but close to primary user were not allocated because of the heavy interference that might emanate from the primary user. The fist table in appendix III shows the available channels from Awka location, when the system did allocation in the second table the free channels were allocated as evidenced in channels 26, 28, 30, 32, 34, 36, 38, 40, 42, 44 etc. these channels were free originally from the available channels table. On the second table still in Awka location, when the devices assigned with odd numbers requested for channels the table shows that their demand were met and channels 27, 29, 31, 33, 35, 37, 39, 41, 43 etc were allocated. The system took care of interference by not allocating channel 25 though free from available channel table but close to primary user. In Nkpor location the system also did channel allocation to the free channels as evidenced with channels 22, 26, 28, 30, 34, 36, 42 etc. It should be noted that channels 38 and 40 though free as seen in the available channel table and it also met the simulated test plan but because there are close to primary user, allocation was not made because of interference.

Our system also did the same allocation in Ubulu-Uku location for requesting devices, only free channels 27 and 29 were allocated. Also for the even numbers only 26 and 28 were allocated. The available channel table shows that channels 25, 26, 27, 28, 29, 30, 34, 36, 40 and 43 were free but are close to primary users.

4.11.6 Performance Evaluation

The performance evaluation was done using the test data table in table 4.15 to 4.28. For each table different conditions for allocation was used to see if interference situation was minimized and if allocations were optimized. The results showed that the new system has performed creditable compared to the existing system. In the existing system a lot of assumptions were made to actual existence of white spaces, there were computational complexities, interference between primary user and white space devices and most alarming of all is misdetection of white spaces, all these were associated with the existing system. In our new system, the best fitness for the channels allocations were computed, the parameters for our evolution were carefully formulated and it formed the inference rules used for our knowledge base.

The new system was able to overcome propagation model inaccuracies; this was done by actually measuring the received power in each pixel. Since the location and transmission power of TV towers is known and varies slowly over time. This can be used when calculating TVWSs instead of using inaccurate propagation models.

4.11.7 Limitations of the System

The following are the limitations of the system:

i) The proposed performance model is used in a simulated environment; the robustness of the model will only make significant impact in the real life environment.

ii) Unable to acquire a secured network for actual linking of the performance model of the new Tv white space optimization system.

4.11.8 Program Testing

Software testing is the process of evaluating a system or its component(s) with the intent to find whether it satisfies the specified requirements or not. There are many different types of software testing but the two main categories are dynamic testing and static testing. Dynamic testing is an assessment that is conducted while the program is executed; static testing, on the other hand, is an examination of the program's code and associated documentation. Dynamic and static methods were used in testing this Tv white space optimization model system.

The static testing done: includes reviewing of the documents (including source code for the locations, genetic algorithm module and allocation module) such as transmitter location, inspection of the codes physically without executing them to ensure that it perform the desired goal for this study.

Dynamic Testing: In dynamic testing the software code is executed to demonstrate the result of running tests. It's done during validation process. Each of the unit (source code for the locations, genetic algorithm module and allocation module) was tested as separate unit using unit testing and then tested to see how they integrate with each other (integration test) and finally the whole system was tested (system testing).

All the modules in the software were then linked up and integration testing was carried out, first the available channels in each locations was selected and thereafter the devices were simulated using random number generation and some devices were assigned odd numbers while others even numbers. Once this part of the test was successful, the allocation table begins to change its status depending on availability of the channels.

The following test were further carried out to ensure the model meets the expected result

i) Black box testing: Internal system design was not considered in this type of test. The tests were based on requirements and functionality.

ii) White box testing: This testing also known as Glass box testing was done to ensure that the internal logic of an application's code perform what it is suppose to such as checking that the control cost for the TV white space optimization using genetic algorithm was properly done, that the code statements, branches, paths, conditions do what they are suppose to.

iii) Functional testing: Ensures that the output gotten was what was required or originally desired.

vi) Usability testing: User-friendliness check. Application flow is tested, can new user understand the application easily, proper help documented whenever user gets stuck at any point. Basically system navigation was also checked in this testing. As shown in the appendix by sample output / input the performance model was made as user friendly as possible without compromising functionality.

vii) Install/uninstall testing: Tested for full, partial, or upgrade install/uninstall processes on different operating systems under different hardware, software environment.

4.12 System Security

Computer security is the protection of the items you value, called the assets of a computer or computer system. There are many types of assets, involving hardware, software, data, people, processes, or combinations of these (Pfleeger et al.2015). System security can be seen as a system of safeguards for protecting the system as well as data/information against unauthorized access that can result to misuse, malicious damage or complete loss of data. Every system is always compromised to some extent, and a basic design goal of any system should be that it can continue to operate appropriately in the presence of a penetration. Vulnerabilities include fraudulent identification and authorization, abuse of access privileges, compromises in the integrity of data, and artificially induced disruptions or delays of service. Implementation of good system security depends on several principles:

i) Physical security: the first level of security concerns the physical environment, including the IT resources and people. Servers, network hardware and related equipment must be securely stored and protected because physical access to a computer represent an entry point into the system and must be controlled and protected. Servers if possible should be equipped with locks.

ii) Password: strong password should be use to avoid hacker gaining access illegally to the system, the password should be a combination of alphabets, number and special characters, this will help prevent the use of brute force attack or dictionary attack method to access the system.

iii) Permissions setting: The major security mechanism for this system is the use of permission to group a set of users. The permission settings include Read, Write and Execute. The fitness function is able to read a file only, channel allocations are able to read from the available channels source node but not able to write to the source node but they can write to themselves, and the source node is able to read, write and execute across the different transmitter locations.

The major type of security threats to consider when using this Tv white space optimization system include the following:

i) Interception: This refers to the situation that an unauthorized party has gained access to a service or data. A typical example of interception is where communication between two parties has been overheard by someone else.

Interception also happens when data are illegally copied, for example, after breaking into a person's private directory in a file system.

ii) Interruption: This occurs when a file is corrupted or lost. In general, interruption refers to the situation in which services or data become unavailable, unusable, destroyed, and so on. In this sense, denial of service attacks by which someone maliciously attempts to make a service inaccessible to other parties is a security threat that classifies as interruption.

iii) Modification involve unauthorized changing of data or tampering with a service so that it no longer adheres to its original specifications. Examples of modifications include intercepting and subsequently changing transmitted data, tampering with database entries, and changing a program so that it secretly logs the activities of its user.

iv) Fabrication: refers to the situation in which additional data or activities are generated that would normally not exist.

4.13 Procedure for Software Installation

The Software installation is very easy for anyone to accomplish. All relevant preparations and details needed have been documented on the software for any machine. First of all you need to install web server before installing the software. To install the software copy the software folder to www directory of the server, automatically the software will be installed on the system. The software folder can be in either of the following CD/DVD ROM or flash drive. To test for successful installation you can run the software from any browser by typing localhost then chose the software. This will display the home page of the system. Once the home page is displayed, you can now execute any task you want through the system menu.

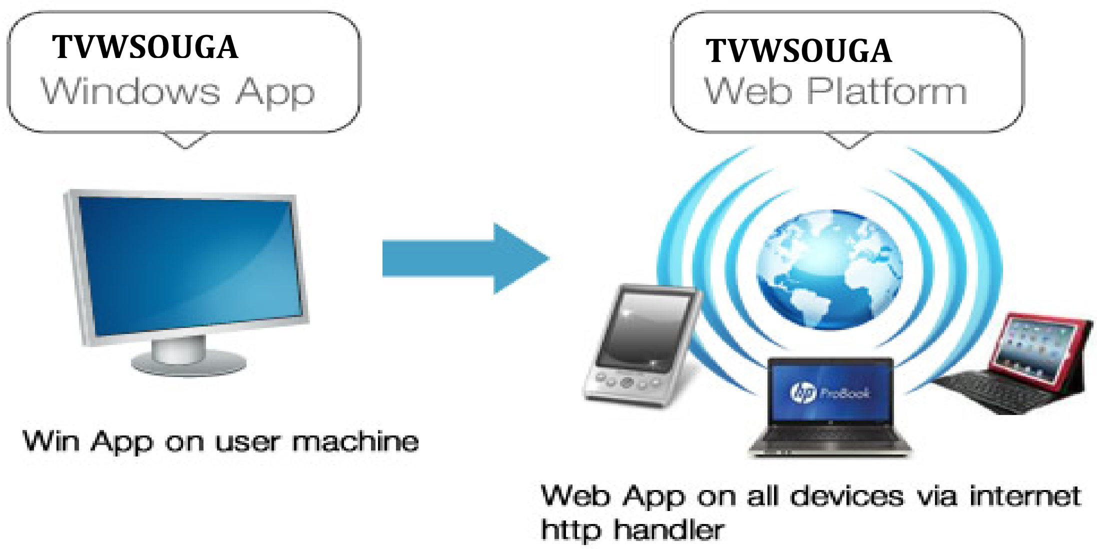
4.13.1 White Space Optimizer on Web Platform

Running TV White Space Optimization Software (TVWSOUGA) on the web is a good idea seeing the flexibility of the platform it is been developed on. The system can be uploaded as an applet to the web to enable user access the system from any location This will drive more clients to using the service allowing it to be more efficient amongst users. The access to the database information will be open to any broadcasting device. For various reasons, using TVWSOUGA on the web over a wireless network will provide:

i) Quick access to TVWSOUGA simply from a browser at anytime, anywhere

ii) System flexibility such that it can be used without having to install each time on a new machine

iii) Access to different database services which will enhance the communication of White Space Devices is guaranteed



4.13.2 Detailed Implementation Plan

System implementation involves the coordination of the systems' components in order to make it not just workable but highly successful. It consists of the following tasks, systems conversion, final documents compilation and users training. System conversion is the process of changing from old information system to a new one. It involves converting hardware, software, data and files. While hardware conversion, involves changing over the physical components of the old system to those required by the new system. Software conversion has to do with changing over from an old information system to a new one.

4.13.3 System Conversion

This is the process of changing the old information system. System changeover is the process of putting the new system online and retiring the old system. The four system changeover approaches description, their advantages, disadvantages and the implications of using each of these approaches for the performance model of the new TVWSOUGO system is as follows

Direct Cutover Conversion: is a direct approach where old system is cut and over written by new system. The direct cutover approach causes the changeover from the old system to the new system to occur immediately when the new system becomes operational.

The advantage is that this is the least expensive method among all four but involves high risk of data loss. With the direct cutover method, the system cannot be reverted to the old system as a backup option.

The disadvantage Direct cutover involves more risks of total system failure and if there is a system failure then it will be difficult to store information but as if there is lack of funds, this approach will be the possible option because of its low cost application among all four approaches.

Parallel Operation Conversion: occurs when two things run simultaneously, so here two operations run simultaneously. The parallel operation changeover method allows both the old and the new systems to operate fully for a specified period when users and the IT group are satisfied that the new system operates correctly, the old system is terminated.

The advantage parallel operation is having very low amount of risk if the new system does not work correctly, the company can use the old system as a backup.

The disadvantage is that it is the most costly changeover method. Data have to be entered in both systems. Users must work in both system and this result in increased workload and processing delays but this can be remedy by implement a common interface for both the new and old system so that data is only entered once.

Pilot Operation Conversion: The pilot operation changeover method involves implementing the complete new system at a selected location of the company. The group that uses the new system first is called the pilot site. The old system continues to operate for the entire organization including the pilot site. After the system proves successful at the pilot site, it is implemented in the rest of the organization, usually using direct cutover method or parallel method. Pilot operation is combination of parallel operation and direct cutover methods.

The Advantage of Pilot site assures the working of new system and reduces the risk of system failure. This is also less expensive than the parallel operation as only at one section runs both systems for limited period.

This is less expensive and safer approach as its combination of both direct cutover and parallel operation.

Phased Operation Conversion: Phased operation works in different phases or stages. Implementation of new system in modules or stages is phased operation.

This is also a combination of direct cutover and parallel similar to pilot operation. But in this approach the entire system is provided to some users instead a part of system to all users.

The advantage of phased changeover is that the risk of errors or failures is limited to the implemented module only and also phased operation is less expensive than the full parallel operation. The disadvantage is that in some cases, phased operation can cost more than a pilot approach where the system involves a large number of separate phases. As is the case with this new system where the different leafs and studs if tested in phased will be more costly.

4.13.4 Recommended Procedures

From the four possible approaches, it is very clear that direct cutover or parallel approach alone is not suitable for the new system because of drawbacks like high risk or high cost, also phased operation is not a suitable approach as we know there are lot of phases involve in our system and also limited fund. Therefore the pilot operation is the most recommended approach for the new system because this method is cheaper and safer method. Once the model is use successfully in one section of the network then it can be implement across board. In this way it will be implemented under budget and also there will be low risk of system failure.

4.13.5 Training of the Operators

This is very important aspect of system implementation in order for them to be able to operate the new system correctly and obtain benefits. The amount of training required for various categories of personals will depend on the complexity of the system and skills presently available. Handbooks, journals and lectures may be used as aids in training of staff.

4.13.6 Documentation

This describes any document (hardcopy or softcopy) which defines the functional requirements, design, implementation, operation or support arrangements that pertain to a software item or any data used by a software item is known as software documentation. Essentially it is written text that accompanies computer software. It either explains how it operates or how to use it. The following documentations were carried out in this work:

Architectural: This was used to lay out the general requirements that would motivate the existence of a routine.

User: This is used to describe how the software is used.

Code: This is the text attached which explain various operations. It is used to define and explain the APIs, data structures and algorithm.

Design: This actually took much broader view and emphasizes and was used to explain why the software is designed in that manner.

Trade study: This was integrated because it focuses on one specific aspect of the system and suggests alternate approaches. It could be at the user interface, code, design, or even architectural level.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

In this dissertation, a window-based application was developed and implemented on Java Run Time Environment (JRE) plat form that performs spectrum management. Genetic algorithm was employed as the optimization technique for optimum allocation of free white spaces to requesting WSDs.

Four locations were analyzed and proper sensing technique was used to find out the availability of white space in those environments. The result shows that there were over 60% available channels unutilized in each location under consideration amounting to a total about 1064 MHz available spectrum in the four locations. These available frequencies can comfortably serve requesting WSDs. Apache Derby was used to design the database which is the most important aspect of this work because the information about the free spectra and location were housed by the database in a real time form to avoid the problem of false detection which can cause serious interference on the communicating devices.

The spectrum sensing ability on the TVWS was improved because the dissertation was able to determine at every second the free spectrum holes and allocate devices to such holes. The dissertation also considered the need for continues communication between devices moving from one location to another and with the information provided by real time database switching into free spectrum holes was made possible. Among other things the dissertation was able to make provisions for the information to be provided by the device to the database(s). The information returned from the database(s) to the device, The frequency of update of the database(s) and hence the periodicity with which devices will need to re-consult. The modeling algorithms and device parameters to be used to populate the database(s) was also made possible.

5.2 Conclusion

After researching in TVWS and implementing a geolocation database technique with rule base and genetic algorithm, it can be concluded that it will be very profitable (both economically and in terms of communications QoS) alternative to traditional static communications, solving the lack of spectrum issue at the same time.

Analyzing the results from the database system, it has been demonstrated that putting extra efforts and time in developing a detailed and complete initial design, its later implementation can be simplified considerably. In this way, we do not require large amount of resources and infrastructure, being the results quite good. The small amount of necessary resources for its implementation makes the geolocation technique system a good candidate for commercial developments. However, it should be noted that with more detailed propagation models using terrain data, the required computing resource will become higher. This will also lead to better utilization of white spaces and to more accurate and trustable results.

It should be noted clearly that geolocation technique systems are in their initial development steps and in consequence just the basic functions have been defined. In the future and with the experience, several additional features could be added to the basic functionality of the system, improving QoS and efficiency. However, the dissertation successfully achieved the its scope, the state of art the art of cognitive radio, TVWS and communication was first analyzed and deep knowledge on the subject was acquired and its availability in our locality ascertained. This knowledge was used to successfully implement a geolocation database technique with involvement of rule base and genetic algorithm for proper white space detection and allocation. For public access to the implementation and to enable users access the system from any location, a provision for uploading of the system as an applet to the web was also provided.

5.3 Recommendation

This software is recommended to Federal Communications Commission (FCC) who on November 4, 2008, formerly approved the use of unused spectrum for WSDs. It is also recommended to Google who offered to host the database of available channels (sorted by latitude and longitude) free of charge. Also to Nigeria Communication Commission (NCC) that communication industries in Nigeria rely on their policies.

5.3.1 Areas of Application

The areas of application for deployment of this dissertation are

Many services and applications could benefit from this research work, they include:

i) Wireless low power networks for hotspots and premises in TV bands, as an alternative to the highly congested industrial, scientific, and medical (ISM) band.

ii) Regional-area networking, especially suited to providing Internet in areas with poor wire line infrastructure.

iii) Hot-spot coverage: To provide communications in hot-spots similar to Wi-Fi technology used in public areas.

iv) Machine-to-machine communications: To provide communications between devices for purposes of control and remote monitoring of electricity meters that is smart metering.

v) Wireless Surveillance System: To provide video surveillance and traffic monitoring

vi) 3G/4G networks extension over TVWS, complementing licensed spectrum usage: in particular in femtocells to minimize interference to own macrocells.

vii) Radio transmission station with white space devices utilizing their channels, when their radius of coverage is outside the transmitting range

viii) Traffic management and control (Vehicle to vehicle, Vehicle to Roadside broadcast device Vehicle to central broadcast database.

ix) It will unleash the WiFi revolution when the white space is opened to unlicensed broadband use.

5.3.2 Suggestion for Further Research

After completing this research, it is possible to further extend the optimization of TVWS research in different other ways:

i) The main security purpose of the database system is to ensure that the WSDs receive information from the validated database administrator and that no-one is trying to impersonate it sending invalid information. In the database system implementation, security features were not taken into consideration. However, in real database systems it is essential to develop several security measures such as user authentication (through interfaces with WSDs and Other users), Public key infrastructure (PKI), transport security (Since the interfaces can be defined as HTTP interfaces carrying XML contents, the transport layer security can be performed in the same way as in web pages providing authentication, integrity and confidentiality (TLS, SSL), privacy, encryption etc. Future work should focus on developing the lacking security features of the geo-location database system.

ii) A large scale channel utilization measurement campaign across time and location is needed in order to better understanding how the open spectrum is utilized.

iii) For a better visualization of the benefit of cognitive radio, which is a major player in TVWS utilization a video streaming application can be added on top of the existing architecture.

iv) Dynamic frequency channel selection is one approach to solving local network congestion problem. Other variables, such as transmission range, transmission rate, and packet size can also be tuned adaptively to optimize connectivity performance.

5.3.3 Review of Achievements

The TV White Space Optimization Software (TWHISO) produced has been tested and found to achieve the following:

Discovering of unused channels: One of the prevailing problems in spectrum management is the method of allocation that has made spectrum look scarce because of increase in the need wireless device. In this dissertation, alternative way of serving some wireless devices has been discovered through the use of UHF channels in the terrestrial television bands.

Interference reduction between communication devices: The spectrum management and allocation using geolocation technique in this dissertation reduced the possible occurrence of interference. This was done by making sure that optimal fitness is not adjacent to primary user and occupied channel. If adjacent the system assign a value of 0 which indicate that it is not fit for allocation. If not adjacent the system assign a 1 meaning it is fit for allocation without interference.

Optimal allocation of TVWS to WSDs: The dissertation was able to achieve this due to the nature of the algorithm used, the inference rules were well chosen which was used to form the knowledge base. The system communicates with the knowledge base and all necessary conditions are tested before declaring a channel fit for allocation to WSDs.

Continuity in communication by WSDs: There is continuity in communication between the WSDs. This is being made possible because of the switching ability the dissertation offers. When a WSD is transmitting and moves to another location, it's transmitting channel changes from location A to location B. on location B the WSD is automatically switched to available channel in its new location.

Protection of primary users: With the combination of geolocation technique and sensing, the licensed user of the spectrum is protected with more accuracy than using sensing alone. This dissertation employed geolocation technique with sensing for maximum protection of licensed user of the spectrum. White Space Devices (WSD) are in constant interaction with the database to make sure that any harmful interference is avoided.

Providing channel information: The dissertation provided information on the list of frequencies that could be used within each location. In order to allow variable size bandwidths to be used the dissertation also provided start and end frequencies which are considered more appropriate. In addition the maximum transmit power was provided for each frequency assignment. This would allow the devices to operate accordingly in order to minimize the possible interference or to increase the flexibility of the device.

Increase in spectrum Access: Spectrum access to white spaces would enhance spectrum utilization, while also testing the approach of controlling the interference between different systems directly rather than through the transmission power. The amount of interference generated to the license holder can be controlled by our sensing model capabilities and geolocation database access.

Hybrid combination: Many previous researches in this domain either use sensing techniques alone in detection of spectrum holes or employ the use of geolocation database to identify list of available spectrum holes. This dissertation extended the research by taking into consideration the two separate entities into one for optimum result. The use of geolocation technique and sensing in determining the spectrum holes and protecting the primary users has optimized spectrum usage.

.5.3.4 Benefits of the System

The following are the benefits of this dissertation

Long Range: TVWS are found in the VHF and UHF TV broadcasting frequencies, especially between 474−866 MHz as found in our analysis. At lower frequencies, radio signals have a very long range. As a result, fewer base stations are required for providing the same level of coverage, resulting in cheaper networks as this reduces both capital expenditure on network equipment and network maintenance and operation (e.g. power for base stations) costs. Long signal range is beneficial especially for providing coverage in rural areas, where the alternative solutions are expensive.

Better Speeds: The frequencies used for television broadcasting were chosen in the first place because they were good at transmitting information quickly. Whereas Wi-Fi can shuttle data at 160-300 megabits (Mbps) per second, white-space can do so at 400-800 Mbps per second.

In-Building Penetration: The excellent propagation of TVWS radio signals provides deep in-building coverage, allowing ubiquitous (or near-ubiquitous) coverage. Their non-line-of-sight performance offers the ability to penetrate obstacles such as trees, buildings and rugged terrain.

Free, Unlicensed Spectrum: TVWS are being opened up for new uses on a free and unlicensed basis. Regulators are considering or have already allowed TVWS devices to operate in the TV band provided that they do not cause interference to the primary spectrum users. Free spectrum significantly reduces the costs of operating wireless networks.

Increasing Economic and Social Development of the Country: Proper implementation of TVWS will open up mobile broad and allow for more data usage with the following benefits more productive farming (e.g. through online access to key information), a stimulus to the development of local e-commerce businesses, enhancing delivery of teaching and training materials to rural schools and reducing the cost of health care delivery. Communication with distant family members will be enhanced – for example through video communication – and it will be easier to keep in contact through online social networks.

Globally harmonized spectrum: TV bands are harmonized worldwide, so white space can be expected to be available globally. Having a global marketplace offers the prospect of economies of scale for network equipment and devices. This will spur the development of common standards and technologies while allowing manufacturers to mass-produce equipment driving down unit costs.

Furthermore, recent developmental trends in wireless technologies are not only providing various opportunities for entrepreneurs, but also overhauling the character of entrepreneurship by pioneering new business models. To date, an array of competing wireless technologies have entered the market and these range from Wireless Mesh technology, WiFi, WiMAX (802.16), Cellular such as Universal Mobile Telecommunication Services/Wideband Code Division Multiple Access (UMTS)/WCDMA and High speed Downlink Packet Access (HSPDA), Long-Term Evolution (LTE) and Advanced LTE. To this end, among these developments in the market, wireless mesh networks (WMNs), have indisputably and justifiably been touted as a candidate technology that is set to facilitate ubiquitous connectivity to the end user in underprivileged, under provisioned, and remote areas. The WMNs comprise wireless routers and clients as well as an endowed ability to dynamically self organize, and self configure to the extent of nodes in the network being able to establish and maintain connectivity among themselves. The candidature of this technology justifiably emanates from its characteristic low upfront cost, ease of maintenance, robustness as well as reliable service coverage. Indisputably, WMNs have found applications ranging from broadband home networking, community and neighbourhood networks, enterprise networking, building automation and other public safety areas etc. However, while the currently deployed WMNs provide flexible and convenient services to the clients, the performance, growth and spread of WMNs is still constrained by several design limitations such as limited usable frequency resource. The design constraints are a consequence of WMNs in the unlicensed Industrial, Scientific and Medical (ISM) band being mostly adopted for access communications. Subsequently this adoption renders the WMN susceptible to competition with all other devices in this particular ISM band eg. near by WLANS and Bluetooth devices. Ultimately, the limited bandwidth of the unlicensed bands cannot cope with the evolving network applications and this has led to the spectrum scarcity problem. However, with the discovery of TVWS and proper method of assignment to unlicensed device will provide an opportunity to significantly enhance the performance of WMNs and other wireless technologies. This will no doubt bring a lot of innovations like fostering hundreds of small scale incremental innovations due to the low costs involved.

5.4 Contributions to Knowledge

The following are the contributions to knowledge from this dissertation

(i) It provides a spectrum sensing model that can find the exact location of primary user and overcome the numerous challenges faced by present spectrum sensing methods with interference minimized.

(ii) With the discovery of TVWS and availability within our locality for possible use by WSDs. This will spur entrepreneurs’ to establish companies and improve the economic standard of our country since smart devices and equipments can easily connect to these available channels in an unlicensed manner reducing the overhead cost of running such organizations/industries.

(iii) It improves on spectrum access by the secondary users resulting in significant increase in spectrum utilization.

(iv) The developed program in this dissertation was able to overcome false detection and misdetection of spectrum holes by improving on spectrum sensing ability using geolocation techniques and a combination of rule base and genetic algorithm to give optimal utilization of the available spectrum spaces.

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APPENDIX I (Source Code)

```
<?php
   require_once("util/Dbconfig.php");
   require_once("util/ga.php");
   require_once("util/funcs.php");
         if (isset($_GET['location'])) {
                  $location = $_GET['location'];
         }else{
                  $location = 'AWKA';
         }
   //echo "loc1: ".$location;
    //$cr = new CognitiveRadio($location);
   $availchannels = get_availableChannels($db_con,$location);
   $allocation = display_allocationTable($db_con,$location);
   function get_availableChannels($db_con,$location){
         $id = 1;//echo "loc2: ".$location;
         $c = $db_con->query("SELECT * FROM `availablechannels` WHERE `location` =
'$location'");
         $availchannels = '<table class="table table-hover">
        <thead class="thead-dark">
         <tr>
              <th>SN</th>
              <th>Band</th>
```

```
            <th>Channel No</th>
            <th>Status</th>
          </tr>
        </thead>
        <tbody>
';          while ($r = $c->fetch(PDO::FETCH_BOTH)) {
                if($r['status'] == "FREE"){
              $lblclass = "label label-success";
            }elseif($r['status'] == "OCCUPIED"){
              $lblclass = "label label-warning";
            }elseif($r['status'] == "RESERVED"){
              $lblclass = "label label-danger";
            }
         $availchannels .= '
        <tr>
          <td>'.$id.'</td>
          <td>'.$r['band'].'</td>
          <td>'.$r['channelno'].'</td>
          <td><span class="'.$lblclass.'">'.$r['status'].'</span></td>
        </tr>'; $id += 1;
         }//end while
         $availchannels .= '
              </tbody>
            </table>';
```

```
    return $availchannels;

  }//end function

  ?>

<!DOCTYPE html>

<html>

<head>

        <meta name="viewport" content="width=device-width,
initial-scale=1.0,                    maximum-scale=1.0,                    user-
scalable=no">

        <title>Tv White Space Optimization</title>

        <link href="css/bootstrap.min.css" rel="stylesheet">

        <link href="css/custom.css" rel="stylesheet">

  <link href="css/owl.carousel.css" rel="stylesheet">

  <link href="css/owl.theme.css" rel="stylesheet">

  <link href="css/style.default.css" rel="stylesheet">

        <link rel="stylesheet" type="text/css" href="css/vis.css">

        <link href="css/animate.css" rel="stylesheet">

        <script src="js/modernizr-2.6.2.min.js"></script>

          <script type="text/javascript" src="js/vis.js"></script>

        <script type="text/javascript" src="js/chart.js"></script>

        </head>

<body onload="drawVisualization();">

              <nav class="navbar navbar-default navbar-fixed-top" role="navigation">

          <div class="navbar-header">
```

```
                    <a class="navbar-brand" href="#"> Tv White Space Optimization Using
Genetic Algorithm</a>

              </div>

              <div>

                     <ul class="nav navbar-nav navbar-right">

                        <li id="intromenu">

                               <a href="#intro">Home</a>

                        </li>

                        <li id="gaconsolemenu"><a href="#gaconsole">GA CONSOLE</a></li>

                        <li id="graphmenu"><a href="#graphs">GRAPHS</a></li>

                        <li id="tablesmenu"><a href="#tables">TABLES</a></li>

                        <li><a href="index.html">LOG OUT</a></li>

                     </ul>

              </div>

            </nav>

           <div id="intro" class="clearfix">

                     <div class="item">

                               <div class="container">

                                         <div class="row">

                                                   <div class="col-md-12">

                                                             <h1 data-animate="fadeInUp">Welcome
to Tv White Space Optimization Using Genetic
Algorithm</h1></div></div></div></div>

           </div><!--GA Output--><br/><br/><br/><br/>
```

```
            <div class="row form-wrapper" id="gaconsole"><center>   <h1 class="title"
data-animate="fadeInUp">GA CONSOLE</h1><center><div class="col-md-8">     <h2
class="title" data-animate="fadeInUp">Genetic Algorithm Console</h2><div
name="gaconsole" id="gaconsole">

<?php echo $gaoutput;?></div></div><div class="col-md-4">

<h2 class="title" data-animate="fadeInUp">TRANSMITTER LOCATION</h2>

<ul><li><a href="dashboard.php?location=AWKA">AWKA</a></li><li><a
href="dashboard.php?location=NKPOR">NKPOR</a></li>                        <li><a
href="dashboard.php?location=ASABA">ASABA</a></li>                        <li><a
href="dashboard.php?location=UBULU-UKWU">UBULU-UKWU</a></li></ul>

                </div></div><br/><div class="row form-wrapper" id="graphs"><center>

                        <h1 class="title" data-animate="fadeInUp">GA
GRAPHS</h1></center>

                <div class="col-md-6"><div class="panel panel-default"><div
class="panel-heading">

        <center><h3 class="panel-title">Frequency Graph</h3></center>

                                </div>

                                <div class="panel-body">

                                <p>

                                        <label for="strategy">Strategy:</label>

                                        <select id="strategy">

                                        <option value="continuous" selected>Continuous
(CPU intensive)</option>

                                        <option value="discrete">Discrete</option>

                                        <option value="static">Static</option>

                                        </select>

                                </p>
```

```
                                        <div id="visualization"></div>

                                        <script type="text/javascript"
src="js/streamscanchart.js"></script>

                                        </div>

                              </div>

                    </div>

                    <div class="col-md-6">

                              <div class="panel panel-default">

                                        <div class="panel-heading">

                                                  <center><h3 class="panel-title">3 Dimensional
Frequency Graph</h3></center>

                                        </div>

                                        <div class="panel-body">

                                                  <div class="row">

                                                            <div class="col-md-6">

                                                                      <div id="mygraph">

                                                            </div>


                                                  </div>

                                        </div>

                                        </div>

                              </div>

                    </div>

          </div>
```

```
	<br/>
	<div class="row form-wrapper" id="tables">
		<center>
			<h1 class="title" data-animate="fadeInUp">GA
TABLES</h1><br/><br/>
			<span>Current Location:<?php echo $location;?></span>
		</center>
		<div class="col-md-6">
			<div class="panel panel-default">
				<div class="panel-heading">
					<center><h3 class="panel-title">Available
Channels Table</h3></center>
				</div>
				<div>
					<?php echo $availchannels;?>
				</div>
			</div>

		</div>
		<div class="col-md-6">
			<div class="panel panel-default">
				<div class="panel-heading">
					<center><h3 class="panel-title">Channel
Allocation Optimization Table</h3></center>
				</div>
```

```
                              <div class="panel-body" id="allocation">
                                   <?php echo $allocation;?>


                              </div>
                         </div>
                    </div>
               </div>


               <div class="footer form-wrapper" style="width: 100%;">
                    Project Software designed and implemented by Wilfred Adigwe &copy;
2017
               </div>
               <!---SCRIPT BASE-->


               <script src="js/jquery-1.11.0.min.js"></script>
          <script src="js/bootstrap.min.js"></script>
          <!-- waypoints for scroll spy -->
          <script src="js/waypoints.min.js"></script>
          <!-- owl carousel -->
          <script src="js/owl.carousel.min.js"></script>


          <!-- jQuery scroll to -->
          <script src="js/jquery.scrollTo.min.js"></script>
```

```
        <!-- main js file -->

        <script src="js/front.js"></script>

        <script type="text/javascript" src="js/gascript.js"></script>

</body>

</html>

<?php

ob_start();

 $db_host = "localhost";

 $db_name = "ga";

 $db_user = "root";

 $db_pass = "";

  try{

    $db_con = new
PDO("mysql:host={$db_host};dbname={$db_name}",$db_user,$db_pass);

  $db_con->setAttribute(PDO::ATTR_ERRMODE, PDO::ERRMODE_EXCEPTION);

 }

 catch(PDOException $e){

  echo $e->getMessage();

 }

?>

<?php

/*******************************************************************
**

/ GA : Genetic Algorithms  main page

/
```

```
/*****************************************************************
**/

//$solution_phrase = $_GET['solution_phrase'];

require_once('individual.php');  //supporting individual

require_once('population.php');  //supporting population

require_once('fitnesscalc.php');  //supporting fitnesscalc

require_once('algorithm.php');  //supporting fitnesscalc

$solution_phrase= "00110111";//"A genetic algorithm found!";

algorithm::$uniformRate=0.50;

algorithm::$mutationRate=0.05;

algorithm::$poolSize=25; /* crossover how many to select in each pool to breed from
*/

$initial_population_size=50;            //how many random individuals are in initial
population (generation 0)

algorithm::$max_generation_stagnant=400;  //maximum number of unchanged
generations terminate loop

algorithm::$elitism=true;  //keep fittest individual  for next gen

$lowest_time_s=100.00; //keeps track of lowest time in seconds

$generationCount = 0;

$generation_stagnant=0;

$most_fit=0;

$most_fit_last=400;

$gaoutput = "\nUniformRate (crosssover point  where to break gene string)
:".algorithm::$uniformRate;

$gaoutput .= "<br/>mutationRate (what % of genes change for each mutate)
:".algorithm::$mutationRate;

$gaoutput .= "<br/>PoolSize (crossover # of  individuals to select in each pool
):".algorithm::$poolSize;
```

```
$gaoutput .= "<br/>Initial population # individuals:".$initial_population_size;

$gaoutput .= "<br/>elitism (keep best individual each generation true=1)
:".algorithm::$elitism;

       // Set a candidate solution static class

       fitnesscalc::setSolution($solution_phrase);

$gaoutput .= "\<br/>Max Fitness is :".fitnesscalc::getMaxFitness();

$gaoutput .= "\n---------------------------------------------<br/>";

       // Create an initial population

                    $time1 = microtime(true);

      $myPop = new population($initial_population_size, true);

            // Evolve our population until we reach an optimum solution

             while ($myPop->getFittest()->getFitness() > fitnesscalc::getMaxFitness())

                                  {

           $generationCount++;

                                  $most_fit=$myPop->getFittest()->getFitness();

                          $myPop = algorithm::evolvePopulation($myPop); //create a new
generation

                            if ($most_fit < $most_fit_last)

                          {

                                  // $gaoutput .= " *** MOST FIT ".$most_fit." Most fit
last".$most_fit_last;

                                   $gaoutput .= "<br/> Generation: " .$generationCount."
(Stagnant:".$generation_stagnant.") Fittest: ".
$most_fit."/".fitnesscalc::getMaxFitness() ;

                                   $gaoutput .= "  Best: ". $myPop->getFittest()."<br/>";

                                     $most_fit_last=$most_fit;

                                     $generation_stagnant=0; //reset stagnant generation counter

                          }
```

```
                      else
                        $generation_stagnant++; //no improvement increment may want to
end early
                                          if ( $generation_stagnant >
algorithm::$max_generation_stagnant)
                     {
                               $gaoutput .= "<br/>-- Ending TOO MANY
(".algorithm::$max_generation_stagnant.") stagnant generations unchanged. Ending
APPROX solution below \n..)<br/>";
                        break;
                     }
                         } //end of while loop
                           //we're done
                    $time2 = microtime(true);
      $gaoutput .= "Solution at generation: ".$generationCount. " time: ".round($time2-
$time1,2)."s<br/>";
                    $gaoutput .= "\n-------------------------------------------------------<br/>";
                    $gaoutput .= "\nGenes   : ".$myPop->getFittest()."<br/>" ;
                    $gaoutput .= "\nSolution: ".implode("",fitnesscalc::$solution)."<br/>";
//convert array to string
                    $gaoutput .= "\n-------------------------------------------------------<br/>";
                    //echo $gaoutput;
?> <?php
          require_once("Dbconfig.php");
          $location = strip_tags($_GET['location']);
          if (isset($_GET['location'])) {
                    $location = $_GET['location'];
          }else{
```

```
            $location = 'AWKA';
        }
        function resetAction($db_con,$location)
        {
        $c = $db_con->exec("UPDATE allocation SET action = 'NO_ACTION'");
        }
        function display_allocationTable($db_con,$location)
        {
                resetAction($db_con,$location);
                $flag = mt_rand(1,10);
                 $query = "SELECT * FROM `ga`.`allocation` WHERE `location` =
'$location'";////echo $location;
                $s = $db_con->query($query);
                /*if(is_object($s)){
                    //echo "$s is an Object".$s;
                }*/
                $table = '<table class="table table-hover">
                    <thead>
                        <tr>
                            <th>SN</th>
            <th>Band</th>
            <th>Channel No</th>
            <th>Status</th>
            <th>Action</th>
                        </tr>
                    </thead>
```

```
                    <tbody>';$id = 1;
                    $action;//echo "location".$location;
                    while ( $r = $s->fetch(PDO::FETCH_BOTH)) {
                        $action =
doAllocation($db_con,$r['channelno'],$flag,$location);
                        if($action == "ALLOCATE"){
    $lblclass = "label label-success";
}elseif($action == "NO_ACTION"){
    $lblclass = "label label-info";
}elseif($action == "DO_NOT_ALLOCATE"){
    $lblclass = "label label-danger";
}
                        $table .= '
                <tr>
                    <td>'.$id.'</td>
                    <td>'.$r['band'].'</td>
                    <td>'.$r['channelno'].'</td>
                    <td>'.$r['status'].'</td>
                    <td><span class="'.$lblclass.'">'.$action.'</span></td>
                </tr>'; $id += 1;
                ////echo "$s is an Object".$s;
                    }
                    $table .= '</tbody>
                        </table>';
                    return $table;
    }
```

```
function getChannelUp($channelno)
{
	$ans;
	if($channelno == 21){
		$ans = $channelno;
	}else{
		$ans = $channelno - 1;
	}
	return $ans;
	//$s = $db_con->query("SELECT * FROM ")
}
function getChannelDown($channelno)
{
	$ans;
	if($channelno == 70){
		$ans = $channelno;
	}else{
		$ans = $channelno + 1;
	}
	return $ans;
}

function getStatus($db_con,$channelno,$location)
{
	$val;
```

```
			$s = $db_con->query("SELECT * FROM allocation WHERE 
channelno = '$channelno' AND location = '".$location."'");

			while ($r = $s->fetch(PDO::FETCH_ASSOC)) {

				$val = $r['status']; //echo "Status: ".$r['status'];

			}

			return $val;

		}

		 function is_odd($val){

			$ans;

			if(($val % 2) != 0){

				$ans = true;

			}else{

				$ans = false;

			}

			return $ans;

		}

		 function doAllocation($db_con,$curChannel,$flag,$location){

			$ans;

			if(is_odd($flag)){

				$ans = 
allocateOddChannels($db_con,$curChannel,$location);

			}else{

				$ans = 
allocateEvenChannels($db_con,$curChannel,$location);

			}

			return $ans;

		}
```

```
function allocateOddChannels($db_con,$curChannel,$location){

    $action = "NO_ACTION";

    $curChannelStatus = getStatus($db_con,$curChannel,$location);

    $upChannelStatus =
getStatus($db_con,getChannelUp($curChannel),$location);

    $downChannelStatus =
getStatus($db_con,getChannelDown($curChannel),$location);

    if(is_odd($curChannel)){

        if($curChannelStatus == 'FREE'){

            if ($upChannelStatus == 'FREE' &&
$downChannelStatus == 'FREE') {

                $action = "ALLOCATE";

            }elseif (($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'FREE' &&
$downChannelStatus == 'OCCUPIED') || ($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'OCCUPIED')) {

                $action = "DO_NOT_ALLOCATE";

            }elseif(($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'RESERVED') || ($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'RESERVED') ||($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'OCCUPIED')){

                $action = "NO_ACTION";

            }


        }elseif ($curChannelStatus == 'OCCUPIED') {

            $action = "DO_NOT_ALLOCATE";

        }elseif ($curChannelStatus == 'RESERVED') {

            $action = "NO_ACTION";
```

```
                }
            }
            return $action;
        }
         function allocateEvenChannels($db_con,$curChannel,$location){
            $action = "NO_ACTION";
            $curChannelStatus = getStatus($db_con,$curChannel,$location);
            $upChannelStatus =
getStatus($db_con,getChannelUp($curChannel),$location);
            $downChannelStatus =
getStatus($db_con,getChannelDown($curChannel),$location);
            if(!is_odd($curChannel)){
                if($curChannelStatus == 'FREE'){
                    if ($upChannelStatus == 'FREE' &&
$downChannelStatus == 'FREE') {
                        $action = "ALLOCATE";
                    }elseif (($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'FREE' &&
$downChannelStatus == 'OCCUPIED') || ($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'OCCUPIED')) {
                        $action = "DO_NOT_ALLOCATE";
                    }elseif (($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'RESERVED') || ($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'FREE') || ($upChannelStatus == 'OCCUPIED' &&
$downChannelStatus == 'RESERVED') ||($upChannelStatus == 'RESERVED' &&
$downChannelStatus == 'OCCUPIED')) {
                        $action = "NO_ACTION";
                    }
                    }elseif ($curChannelStatus == 'OCCUPIED') {
```

```
                    $action = "DO_NOT_ALLOCATE";
                }elseif ($curChannelStatus == 'RESERVED') {
                    $action = "NO_ACTION";
                }
            }
            return $action;
        }
?> <!DOCTYPE html>
<html>
  <head>
    <meta charset="utf-8">
    <meta http-equiv="X-UA-Compatible" content="IE=edge">
    <title>Bootstrap Dashboard by Bootstrapious.com</title>
    <meta name="description" content="">
    <meta name="viewport" content="width=device-width, initial-scale=1">
    <meta name="robots" content="all,follow">
    <!-- Bootstrap CSS-->
    <link rel="stylesheet" href="css/bootstrap.min.css">
    <!-- Google fonts - Roboto -->
    <link rel="stylesheet"
href="https://fonts.googleapis.com/css?family=Poppins:300,400,700">
    <!-- theme stylesheet-->
    <link rel="stylesheet" href="css/style.default.css" id="theme-stylesheet">
    <!-- Custom stylesheet - for your changes-->
    <link rel="stylesheet" href="css/custom.css">
    <!-- Favicon-->
```

```
    <link rel="shortcut icon" href="img/favicon.ico">

    <link rel="stylesheet" type="text/css" href="css/vis.css">

    <script type="text/javascript" src="js/vis.js"></script>

    <script type="text/javascript" src="js/chart.js"></script>

    <!-- Font Awesome CDN-->

    <!-- you can replace it by local Font Awesome-->

    <script src="https://use.fontawesome.com/99347ac47f.js"></script>

    <!-- Font Icons CSS-->

    <link rel="stylesheet"
href="https://file.myfontastic.com/da58YPMQ7U5HY8Rb6UxkNf/icons.css">

    <!-- Tweaks for older IEs--><!--[if lt IE 9]>

        <script src="https://oss.maxcdn.com/html5shiv/3.7.2/html5shiv.min.js"></script>

        <script
src="https://oss.maxcdn.com/respond/1.4.2/respond.min.js"></script><![endif]-->

  </head>

  <body onload="drawVisualization();>

    <div class="page charts-page">

      <!-- Main Navbar-->

      <header class="header">

        <nav class="navbar">

          <!-- Search Box-->

          <div class="search-box">

            <button class="dismiss"><i class="icon-close"></i></button>

            <form id="searchForm" action="#" role="search">

              <input type="search" placeholder="What are you looking for..." class="form-
control">

            </form>
```

```
</div>

<div class="container-fluid">

 <div class="navbar-holder d-flex align-items-center justify-content-between">

  <!-- Navbar Header-->

  <div class="navbar-header">

   <!-- Navbar Brand --><a href="index.html" class="navbar-brand">

    <div class="brand-text brand-big hidden-lg-down"><span>TvWSOUGA
</span><strong>Dashboard</strong></div>

    <div class="brand-text brand-small"><strong>GA</strong></div></a>

   <!-- Toggle Button--><a id="toggle-btn" href="#" class="menu-btn
active"><span></span><span></span><span></span></a>

  </div>

  <!-- Navbar Menu -->

  <ul class="nav-menu list-unstyled d-flex flex-md-row align-items-md-center">

   <!-- Search-->

   <li class="nav-item d-flex align-items-center"><a id="search" href="#"><i
class="icon-search"></i></a></li>

   <!-- Notifications-->

   <li class="nav-item dropdown"> <a id="notifications" rel="nofollow" data-
target="#" href="#" data-toggle="dropdown" aria-haspopup="true" aria-
expanded="false" class="nav-link"><i class="fa fa-bell-o"></i><span class="badge bg-
red">12</span></a>

    <ul aria-labelledby="notifications" class="dropdown-menu">

     <li><a rel="nofollow" href="#" class="dropdown-item">

       <div class="notification">

        <div class="notification-content"><i class="fa fa-envelope bg-
green"></i>You have 6 new messages </div>

        <div class="notification-time"><small>4 minutes ago</small></div>
```

```
              </div></a></li>

            <li><a rel="nofollow" href="#" class="dropdown-item">

              <div class="notification">

                <div class="notification-content"><i class="fa fa-twitter bg-
blue"></i>You have 2 followers</div>

                <div class="notification-time"><small>4 minutes ago</small></div>

              </div></a></li>

            <li><a rel="nofollow" href="#" class="dropdown-item">

              <div class="notification">

                <div class="notification-content"><i class="fa fa-upload bg-
orange"></i>Server Rebooted</div>

                <div class="notification-time"><small>4 minutes ago</small></div>

              </div></a></li>

            <li><a rel="nofollow" href="#" class="dropdown-item">

              <div class="notification">

                <div class="notification-content"><i class="fa fa-twitter bg-
blue"></i>You have 2 followers</div>

                <div class="notification-time"><small>10 minutes ago</small></div>

              </div></a></li>

            <li><a rel="nofollow" href="#" class="dropdown-item all-notifications text-
center"> <strong>view all notifications                    </strong></a></li>

          </ul>

        </li>

        <!-- Messages               -->

        <li class="nav-item dropdown"> <a id="messages" rel="nofollow" data-
target="#" href="#" data-toggle="dropdown" aria-haspopup="true" aria-
expanded="false" class="nav-link"><i class="fa fa-envelope-o"></i><span class="badge
bg-orange">10</span></a>
```

```
<ul aria-labelledby="notifications" class="dropdown-menu">
 <li><a rel="nofollow" href="#" class="dropdown-item d-flex">
   <div class="msg-profile"> <img src="img/avatar-1.jpg" alt="..." class="img-fluid rounded-circle"></div>
   <div class="msg-body">
    <h3 class="h5">Jason Doe</h3><span>Sent You Message</span>
   </div></a></li>
 <li><a rel="nofollow" href="#" class="dropdown-item d-flex">
   <div class="msg-profile"> <img src="img/avatar-2.jpg" alt="..." class="img-fluid rounded-circle"></div>
   <div class="msg-body">
    <h3 class="h5">Frank Williams</h3><span>Sent You Message</span>
   </div></a></li>
 <li><a rel="nofollow" href="#" class="dropdown-item d-flex">
   <div class="msg-profile"> <img src="img/avatar-3.jpg" alt="..." class="img-fluid rounded-circle"></div>
   <div class="msg-body">
    <h3 class="h5">Ashley Wood</h3><span>Sent You Message</span>
   </div></a></li>
 <li><a rel="nofollow" href="#" class="dropdown-item all-notifications text-center"> <strong>Read all messages    </strong></a></li>
</ul>
</li>
<!-- Logout    -->
<li class="nav-item"><a href="login.html" class="nav-link logout">Logout<i class="fa fa-sign-out"></i></a></li>
</ul>
</div>
```

```
      </div>
     </nav>
    </header>
    <div class="page-content d-flex align-items-stretch">
     <!-- Side Navbar -->
     <nav class="side-navbar">
      <!-- Sidebar Header-->
      <div class="sidebar-header d-flex align-items-center">
       <div class="avatar"><img src="img/avatar-1.jpg" alt="..." class="img-fluid
rounded-circle"></div>
       <div class="title">
        <h1 class="h4">Adigwe Wilfred</h1>
        <p>Designer</p>
       </div>
      </div>
      <!-- Sidebar Navidation Menus--><span class="heading">Main</span>
      <ul class="list-unstyled">
       <li class="active"> <a href="./"><i class="icon-home"></i>Home</a></li>
      </ul><span class="heading">Extras</span>
     </nav>
     <div class="content-inner">
      <!-- Page Header-->
      <header class="page-header">
       <div class="container-fluid">
        <h2 class="no-margin-bottom">Charts</h2>
       </div>
```

```
</header>

<!-- Breadcrumb-->

<ul class="breadcrumb">

  <div class="container-fluid">

    <li class="breadcrumb-item"><a href="login.html">Home</a></li>

    <li class="breadcrumb-item active">Charts</li>

  </div>

</ul>

<!-- Charts Section-->

<section class="charts">

  <div class="container-fluid">

    <div class="row">

      <!-- Line Charts-->

      <div class="col-lg-8">

        <div class="line-chart-example card">

          <div class="card-close">

            <div class="dropdown">

              <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>

              <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>

            </div>

          </div>

          <div class="card-header d-flex align-items-center">

            <h3 class="h4">Line Chart Example</h3>
```

```
        </div>
        <div class="card-body">
          <canvas id="lineChartExample"></canvas>
        </div>
      </div>
    </div>
    <div class="col-lg-4">
      <div class="line-chart-example card no-margin-bottom">
        <div class="card-close">
          <div class="dropdown">
            <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
            <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Line Chart Example</h3>
        </div>
        <div class="card-body">
          <canvas id="lineChartExample1"></canvas>
        </div>
      </div>
      <div class="line-chart-example card">
        <div class="card-close">
```

```
          <div class="dropdown">
            <button type="button" id="closeCard" data-toggle="dropdown" aria-
haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-
ellipsis-v"></i></button>
            <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a
href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a
href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-body">
          <canvas id="lineChartExample2"></canvas>
        </div>
      </div>
    </div>
    <!-- Bar Charts-->
    <div class="col-lg-4">
      <div class="bar-chart-example card no-margin-bottom">
        <div class="card-close">
          <div class="dropdown">
            <button type="button" id="closeCard" data-toggle="dropdown" aria-
haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-
ellipsis-v"></i></button>
            <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a
href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a
href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Bar Chart Example</h3>
```

```
          </div>
          <div class="card-body">
            <canvas id="barChart1"></canvas>
          </div>
        </div>
        <div class="line-chart-example card">
          <div class="card-close">
            <div class="dropdown">
              <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
              <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
            </div>
          </div>
          <div class="card-body">
            <canvas id="barChart2"></canvas>
          </div>
        </div>
      </div>
      <div class="col-lg-8">
        <div class="bar-chart-example card">
          <div class="card-close">
            <div class="dropdown">
              <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
```

```
<div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Bar Chart Example</h3>
        </div>
        <div class="card-body">
          <canvas id="barChartExample"></canvas>
        </div>
      </div>
    </div>
    <!-- Doughnut Chart -->
    <div class="col-lg-6">
      <div class="pie-chart-example card">
        <div class="card-close">
          <div class="dropdown">
            <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
            <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Doughnut  Chart Example</h3>
```

```
          </div>
          <div class="card-body">
            <p>
              <label for="strategy">Strategy:</label>
              <select id="strategy">
                <option value="continuous" selected>Continuous (CPU
intensive)</option>
                <option value="discrete">Discrete</option>
                <option value="static">Static</option>
              </select>
            </p>
            <div id="visualization"></div>
            <script type="text/javascript" src="js/streamscanchart.js"></script>
            <!--<canvas id="doughnutChartExample"></canvas>-->
          </div>
        </div>
      </div>
      <!-- Pie Chart -->
      <div class="col-lg-6">
        <div class="pie-chart-example card">
          <div class="card-close">
            <div class="dropdown">
              <button type="button" id="closeCard" data-toggle="dropdown" aria-
haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-
ellipsis-v"></i></button>
              <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a
href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a
href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
```

```
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Pie  Chart Example</h3>
        </div>
        <div class="card-body">
          <div id="mygraph"></div>
      </div>
    </div>
    <!-- Polar Chart-->
    <div class="col-lg-6">
      <div class="polar-chart-example card">
        <div class="card-close">
          <div class="dropdown">
            <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
            <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
          </div>
        </div>
        <div class="card-header d-flex align-items-center">
          <h3 class="h4">Polar Chart Example</h3>
        </div>
        <div class="card-body">
          <canvas id="polarChartExample"></canvas>
```

```
            </div>
          </div>
        </div>
        <!-- Radar Chart-->
        <div class="col-lg-6">
          <div class="radar-chart-example card">
            <div class="card-close">
              <div class="dropdown">
                <button type="button" id="closeCard" data-toggle="dropdown" aria-haspopup="true" aria-expanded="false" class="dropdown-toggle"><i class="fa fa-ellipsis-v"></i></button>
                <div aria-labelledby="closeCard" class="dropdown-menu has-shadow"><a href="#" class="dropdown-item remove"> <i class="fa fa-times"></i>Close</a><a href="#" class="dropdown-item edit"> <i class="fa fa-gear"></i>Edit</a></div>
              </div>
            </div>
            <div class="card-header d-flex align-items-center">
              <h3 class="h4">Radar Chart Example</h3>
            </div>
            <div class="card-body">
              <canvas id="radarChartExample"></canvas>
            </div>
          </div>
        </div>
      </div>
    </div>
  </section>
```

```
        <!-- Page Footer-->
        <footer class="main-footer">
          <div class="container-fluid">
            <div class="row">
              <div class="col-sm-6">
                <p>Your company &copy; 2017-2019</p>
              </div>
              <div class="col-sm-6 text-right">
                <p>Design by <a href="https://bootstrapious.com/admin-templates"
class="external">Bootstrapious</a></p>
                <!-- Please do not remove the backlink to us unless you support further
theme's development at https://bootstrapious.com/donate. It is part of the license
conditions. Thank you for understanding :)-->
              </div>
            </div>
          </div>
        </footer>
      </div>
    </div>
  </div>
  <!-- Javascript files-->
  <script
src="https://ajax.googleapis.com/ajax/libs/jquery/1.11.0/jquery.min.js"></script>
  <script src="js/tether.min.js"></script>
  <script src="js/bootstrap.min.js"></script>
  <script src="js/jquery.cookie.js"> </script>
  <script src="js/jquery.validate.min.js"></script>
```

```
    <script
src="https://cdnjs.cloudflare.com/ajax/libs/Chart.js/2.5.0/Chart.min.js"></script>
    <script src="js/charts-custom.js"></script>
    <script src="js/front.js"></script>
    <!-- Google Analytics: change UA-XXXXX-X to be your site's ID.-->
    <!---->
    <script>
      (function(b,o,i,l,e,r){b.GoogleAnalyticsObject=l;b[l]||(b[l]=
      function(){(b[l].q=b[l].q||[]).push(arguments)});b[l].l=+new Date;
      e=o.createElement(i);r=o.getElementsByTagName(i)[0];
      e.src='//www.google-analytics.com/analytics.js';
      r.parentNode.insertBefore(e,r)}(window,document,'script','ga'));
      ga('create','UA-XXXXX-X');ga('send','pageview');
    </script>
  </body>
</html>
```

APPENDIX II (Channel Allocation Outputs)

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES L

Current Location:AWKA

Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	OCCUPIED
2	482-490MHZ	22	OCCUPIED
3	490-498iKMHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
9	538-546MHZ	29	FREE
10	546-554MHZ	30	FREE
11	554-562MHZ	31	FREE
12	562-570MHZ	32	FREE
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	FREE
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE
25	666-674MHZ	45	FREE
26	674-682MHZ	46	FREE
27	682-690MHZ	47	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	DO_NOT_ALLOCATE
2	482-490MHZ	22	OCCUPIED	NO_ACTION
3	490-498MHZ	23	FREE	DO_NOT_ALLOCATE
4	498-506MHZ	24	OCCUPIED	NO_ACTION
5	506-514MHZ	25	FREE	DO_NOT_ALLOCATE
6	514-522MHZ	26	FREE	NO_ACTION
7	522-530MHZ	27	FREE	ALLOCATE
8	530-538MHZ	28	FREE	NO_ACTION
9	538-546MHZ	29	FREE	ALLOCATE
10	546-554MHZ	30	FREE	NO_ACTION
11	554-562MHZ	31	FREE	ALLOCATE
12	562-570MHZ	32	FREE	NO_ACTION
13	570-578MHZ	33	FREE	ALLOCATE
14	578-586MHZ	34	FREE	NO_ACTION
15	586-594MHZ	35	FREE	ALLOCATE
16	594-602MHZ	36	FREE	NO_ACTION
17	602-610MHZ	37	FREE	ALLOCATE
18	610-618MHZ	38	FREE	NO_ACTION
19	618-626MHZ	39	FREE	ALLOCATE
20	626-634MHZ	40	FREE	NO_ACTION
21	634-642MHZ	41	FREE	ALLOCATE
22	642-650MHZ	42	FREE	NO_ACTION
23	650-658MHZ	43	FREE	ALLOCATE
24	658-666MHZ	44	FREE	NO_ACTION
25	666-674MHZ	45	FREE	ALLOCATE
26	674-682MHZ	46	FREE	NO_ACTION

Awka result 1

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:AWKA

Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	OCCUPIED
2	482-490MHZ	22	OCCUPIED
3	490-498iKMHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
9	538-546MHZ	29	FREE
10	546-554MHZ	30	FREE
11	554-562MHZ	31	FREE
12	562-570MHZ	32	FREE
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	FREE
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE
25	666-674MHZ	45	FREE
26	674-682MHZ	46	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	NO_ACTION
2	482-490MHZ	22	OCCUPIED	DO_NOT_ALLOCATE
3	490-498MHZ	23	FREE	NO_ACTION
4	498-506MHZ	24	OCCUPIED	DO_NOT_ALLOCATE
5	506-514MHZ	25	FREE	NO_ACTION
6	514-522MHZ	26	FREE	ALLOCATE
7	522-530MHZ	27	FREE	NO_ACTION
8	530-538MHZ	28	FREE	ALLOCATE
9	538-546MHZ	29	FREE	NO_ACTION
10	546-554MHZ	30	FREE	ALLOCATE
11	554-562MHZ	31	FREE	NO_ACTION
12	562-570MHZ	32	FREE	ALLOCATE
13	570-578MHZ	33	FREE	NO_ACTION
14	578-586MHZ	34	FREE	ALLOCATE
15	586-594MHZ	35	FREE	NO_ACTION
16	594-602MHZ	36	FREE	ALLOCATE
17	602-610MHZ	37	FREE	NO_ACTION
18	610-618MHZ	38	FREE	ALLOCATE
19	618-626MHZ	39	FREE	NO_ACTION
20	626-634MHZ	40	FREE	ALLOCATE
21	634-642MHZ	41	FREE	NO_ACTION
22	642-650MHZ	42	FREE	ALLOCATE
23	650-658MHZ	43	FREE	NO_ACTION
24	658-666MHZ	44	FREE	ALLOCATE
25	666-674MHZ	45	FREE	NO_ACTION
26	674-682MHZ	46	FREE	ALLOCATE

Awka result 2

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME | GA CONSOLE | GRAPHS | TABLES | LOG OUT

Current Location:AWKA

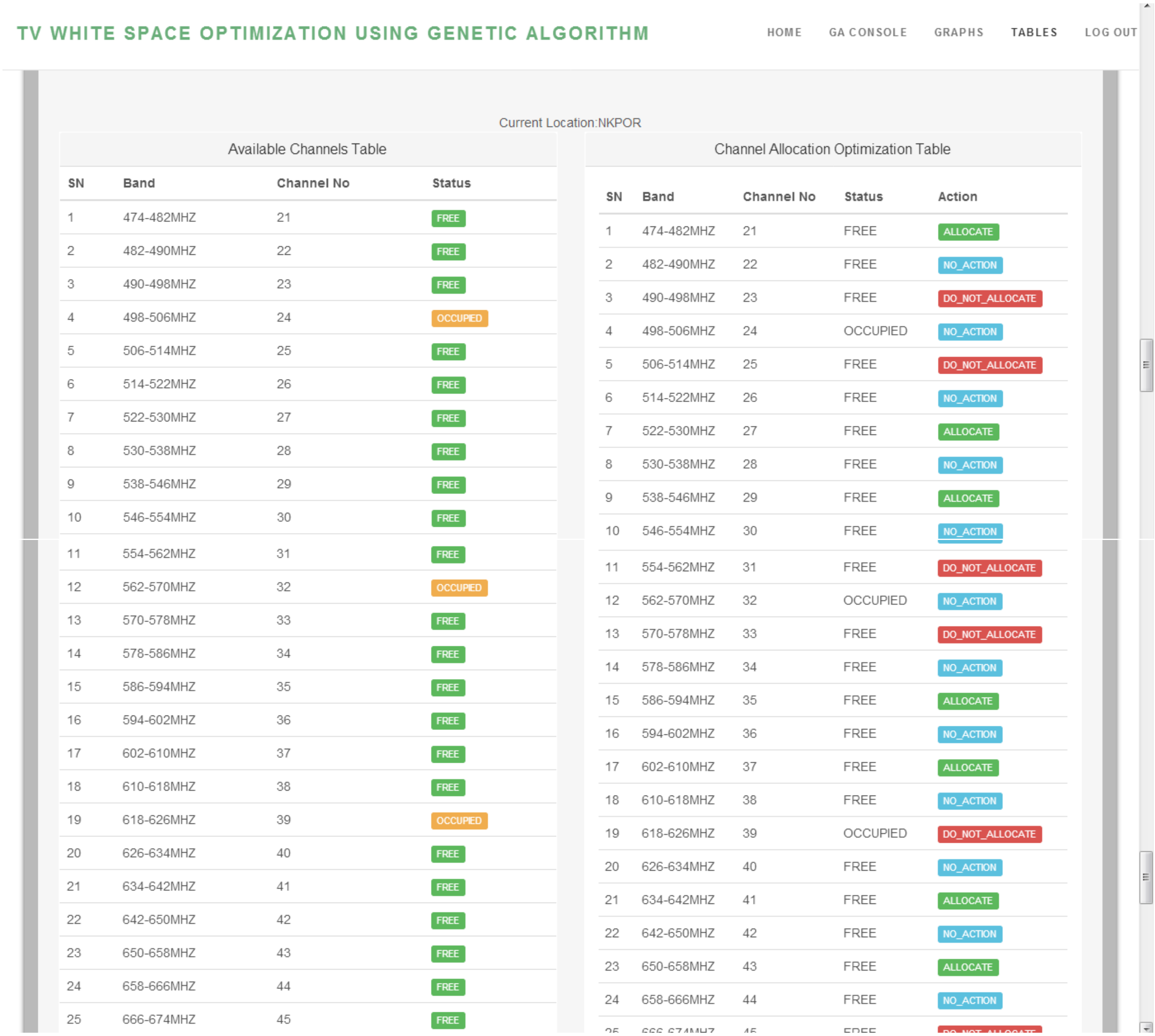
Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	OCCUPIED
2	482-490MHZ	22	OCCUPIED
3	490-498ikMHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
9	538-546MHZ	29	FREE
10	546-554MHZ	30	FREE
[illegible]	[illegible]	[illegible]	[illegible]
12	562-570MHZ	32	FREE
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	FREE
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	DO_NOT_ALLOCATE
2	482-490MHZ	22	OCCUPIED	NO_ACTION
3	490-498MHZ	23	FREE	DO_NOT_ALLOCATE
4	498-506MHZ	24	OCCUPIED	NO_ACTION
5	506-514MHZ	25	FREE	DO_NOT_ALLOCATE
6	514-522MHZ	26	FREE	NO_ACTION
7	522-530MHZ	27	FREE	ALLOCATE
8	530-538MHZ	28	FREE	NO_ACTION
9	538-546MHZ	29	FREE	ALLOCATE
10	546-554MHZ	30	FREE	NO_ACTION
11	554-562MHZ	31	FREE	ALLOCATE
12	562-570MHZ	32	FREE	NO_ACTION
13	570-578MHZ	33	FREE	ALLOCATE
14	578-586MHZ	34	FREE	NO_ACTION
15	586-594MHZ	35	FREE	ALLOCATE
16	594-602MHZ	36	FREE	NO_ACTION
17	602-610MHZ	37	FREE	ALLOCATE
18	610-618MHZ	38	FREE	NO_ACTION
19	618-626MHZ	39	FREE	ALLOCATE
20	626-634MHZ	40	FREE	NO_ACTION
21	634-642MHZ	41	FREE	ALLOCATE
22	642-650MHZ	42	FREE	NO_ACTION
23	650-658MHZ	43	FREE	ALLOCATE
24	658-666MHZ	44	FREE	NO_ACTION

Nkpor



TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:NKPOR

Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	FREE
2	482-490MHZ	22	FREE
3	490-498MHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
9	538-546MHZ	29	FREE
10	546-554MHZ	30	FREE
11	554-562MHZ	31	FREE
12	562-570MHZ	32	OCCUPIED
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	OCCUPIED
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE
25	666-674MHZ	45	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	FREE	ALLOCATE
2	482-490MHZ	22	FREE	NO_ACTION
3	490-498MHZ	23	FREE	DO_NOT_ALLOCATE
4	498-506MHZ	24	OCCUPIED	NO_ACTION
5	506-514MHZ	25	FREE	DO_NOT_ALLOCATE
6	514-522MHZ	26	FREE	NO_ACTION
7	522-530MHZ	27	FREE	ALLOCATE
8	530-538MHZ	28	FREE	NO_ACTION
9	538-546MHZ	29	FREE	ALLOCATE
10	546-554MHZ	30	FREE	NO_ACTION
11	554-562MHZ	31	FREE	DO_NOT_ALLOCATE
12	562-570MHZ	32	OCCUPIED	NO_ACTION
13	570-578MHZ	33	FREE	DO_NOT_ALLOCATE
14	578-586MHZ	34	FREE	NO_ACTION
15	586-594MHZ	35	FREE	ALLOCATE
16	594-602MHZ	36	FREE	NO_ACTION
17	602-610MHZ	37	FREE	ALLOCATE
18	610-618MHZ	38	FREE	NO_ACTION
19	618-626MHZ	39	OCCUPIED	DO_NOT_ALLOCATE
20	626-634MHZ	40	FREE	NO_ACTION
21	634-642MHZ	41	FREE	ALLOCATE
22	642-650MHZ	42	FREE	NO_ACTION
23	650-658MHZ	43	FREE	ALLOCATE
24	658-666MHZ	44	FREE	NO_ACTION
25	666-674MHZ	45	FREE	DO_NOT_ALLOCATE

Nkpor result 1

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:NKPOR

Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	FREE
2	482-490MHZ	22	FREE
3	490-498MHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
11	554-562MHZ	31	FREE
12	562-570MHZ	32	OCCUPIED
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	OCCUPIED
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE
25	666-674MHZ	45	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	FREE	NO_ACTION
2	482-490MHZ	22	FREE	ALLOCATE
3	490-498MHZ	23	FREE	NO_ACTION
4	498-506MHZ	24	OCCUPIED	DO_NOT_ALLOCATE
5	506-514MHZ	25	FREE	NO_ACTION
6	514-522MHZ	26	FREE	ALLOCATE
7	522-530MHZ	27	FREE	NO_ACTION
8	530-538MHZ	28	FREE	ALLOCATE
11	554-562MHZ	31	FREE	NO_ACTION
12	562-570MHZ	32	OCCUPIED	DO_NOT_ALLOCATE
13	570-578MHZ	33	FREE	NO_ACTION
14	578-586MHZ	34	FREE	ALLOCATE
15	586-594MHZ	35	FREE	NO_ACTION
16	594-602MHZ	36	FREE	ALLOCATE
17	602-610MHZ	37	FREE	NO_ACTION
18	610-618MHZ	38	FREE	DO_NOT_ALLOCATE
19	618-626MHZ	39	OCCUPIED	NO_ACTION
20	626-634MHZ	40	FREE	DO_NOT_ALLOCATE
21	634-642MHZ	41	FREE	NO_ACTION
22	642-650MHZ	42	FREE	ALLOCATE
23	650-658MHZ	43	FREE	NO_ACTION
24	658-666MHZ	44	FREE	ALLOCATE
25	666-674MHZ	45	FREE	NO_ACTION

Nkpor result 2

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:NKPOR

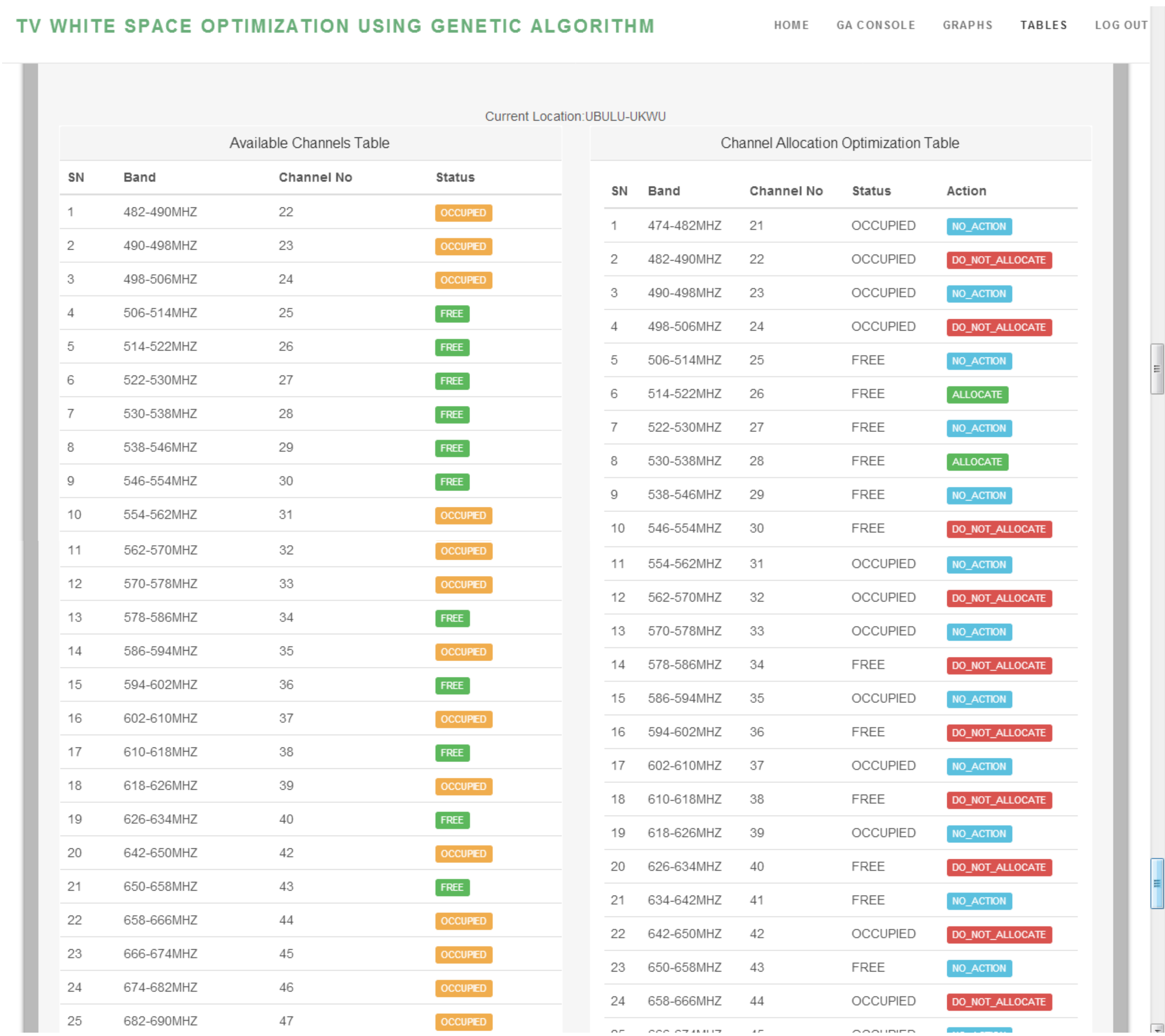
Available Channels Table

SN	Band	Channel No	Status
1	474-482MHZ	21	FREE
2	482-490MHZ	22	FREE
3	490-498MHZ	23	FREE
4	498-506MHZ	24	OCCUPIED
5	506-514MHZ	25	FREE
6	514-522MHZ	26	FREE
7	522-530MHZ	27	FREE
8	530-538MHZ	28	FREE
9	538-546MHZ	29	FREE
11	554-562MHZ	31	FREE
12	562-570MHZ	32	OCCUPIED
13	570-578MHZ	33	FREE
14	578-586MHZ	34	FREE
15	586-594MHZ	35	FREE
16	594-602MHZ	36	FREE
17	602-610MHZ	37	FREE
18	610-618MHZ	38	FREE
19	618-626MHZ	39	OCCUPIED
20	626-634MHZ	40	FREE
21	634-642MHZ	41	FREE
22	642-650MHZ	42	FREE
23	650-658MHZ	43	FREE
24	658-666MHZ	44	FREE
25	666-674MHZ	45	FREE

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	FREE	ALLOCATE
2	482-490MHZ	22	FREE	NO_ACTION
3	490-498MHZ	23	FREE	DO_NOT_ALLOCATE
4	498-506MHZ	24	OCCUPIED	NO_ACTION
5	506-514MHZ	25	FREE	DO_NOT_ALLOCATE
6	514-522MHZ	26	FREE	NO_ACTION
7	522-530MHZ	27	FREE	ALLOCATE
8	530-538MHZ	28	FREE	NO_ACTION
9	538-546MHZ	29	FREE	ALLOCATE
11	554-562MHZ	31	FREE	DO_NOT_ALLOCATE
12	562-570MHZ	32	OCCUPIED	NO_ACTION
13	570-578MHZ	33	FREE	DO_NOT_ALLOCATE
14	578-586MHZ	34	FREE	NO_ACTION
15	586-594MHZ	35	FREE	ALLOCATE
16	594-602MHZ	36	FREE	NO_ACTION
17	602-610MHZ	37	FREE	ALLOCATE
18	610-618MHZ	38	FREE	NO_ACTION
19	618-626MHZ	39	OCCUPIED	DO_NOT_ALLOCATE
20	626-634MHZ	40	FREE	NO_ACTION
21	634-642MHZ	41	FREE	ALLOCATE
22	642-650MHZ	42	FREE	NO_ACTION
23	650-658MHZ	43	FREE	ALLOCATE
24	658-666MHZ	44	FREE	NO_ACTION

Ubulu Uku



Available Channels Table

SN	Band	Channel No	Status
1	482-490MHZ	22	OCCUPIED
2	490-498MHZ	23	OCCUPIED
3	498-506MHZ	24	OCCUPIED
4	506-514MHZ	25	FREE
5	514-522MHZ	26	FREE
6	522-530MHZ	27	FREE
7	530-538MHZ	28	FREE
8	538-546MHZ	29	FREE
9	546-554MHZ	30	FREE
10	554-562MHZ	31	OCCUPIED
11	562-570MHZ	32	OCCUPIED
12	570-578MHZ	33	OCCUPIED
13	578-586MHZ	34	FREE
14	586-594MHZ	35	OCCUPIED
15	594-602MHZ	36	FREE
16	602-610MHZ	37	OCCUPIED
17	610-618MHZ	38	FREE
18	618-626MHZ	39	OCCUPIED
19	626-634MHZ	40	FREE
20	642-650MHZ	42	OCCUPIED
21	650-658MHZ	43	FREE
22	658-666MHZ	44	OCCUPIED
23	666-674MHZ	45	OCCUPIED
24	674-682MHZ	46	OCCUPIED
25	682-690MHZ	47	OCCUPIED

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	NO_ACTION
2	482-490MHZ	22	OCCUPIED	DO_NOT_ALLOCATE
3	490-498MHZ	23	OCCUPIED	NO_ACTION
4	498-506MHZ	24	OCCUPIED	DO_NOT_ALLOCATE
5	506-514MHZ	25	FREE	NO_ACTION
6	514-522MHZ	26	FREE	ALLOCATE
7	522-530MHZ	27	FREE	NO_ACTION
8	530-538MHZ	28	FREE	ALLOCATE
9	538-546MHZ	29	FREE	NO_ACTION
10	546-554MHZ	30	FREE	DO_NOT_ALLOCATE
11	554-562MHZ	31	OCCUPIED	NO_ACTION
12	562-570MHZ	32	OCCUPIED	DO_NOT_ALLOCATE
13	570-578MHZ	33	OCCUPIED	NO_ACTION
14	578-586MHZ	34	FREE	DO_NOT_ALLOCATE
15	586-594MHZ	35	OCCUPIED	NO_ACTION
16	594-602MHZ	36	FREE	DO_NOT_ALLOCATE
17	602-610MHZ	37	OCCUPIED	NO_ACTION
18	610-618MHZ	38	FREE	DO_NOT_ALLOCATE
19	618-626MHZ	39	OCCUPIED	NO_ACTION
20	626-634MHZ	40	FREE	DO_NOT_ALLOCATE
21	634-642MHZ	41	FREE	NO_ACTION
22	642-650MHZ	42	OCCUPIED	DO_NOT_ALLOCATE
23	650-658MHZ	43	FREE	NO_ACTION
24	658-666MHZ	44	OCCUPIED	DO_NOT_ALLOCATE

Ubulu Uku result 1

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:UBULU-UKWU

Available Channels Table

SN	Band	Channel No	Status
1	482-490MHZ	22	OCCUPIED
2	490-498MHZ	23	OCCUPIED
3	498-506MHZ	24	OCCUPIED
4	506-514MHZ	25	FREE
5	514-522MHZ	26	FREE
6	522-530MHZ	27	FREE
7	530-538MHZ	28	FREE
8	538-546MHZ	29	FREE
9	546-554MHZ	30	FREE
10	554-562MHZ	31	OCCUPIED
11	562-570MHZ	32	OCCUPIED
12	570-578MHZ	33	OCCUPIED
13	578-586MHZ	34	FREE
14	586-594MHZ	35	OCCUPIED
15	594-602MHZ	36	FREE
16	602-610MHZ	37	OCCUPIED
17	610-618MHZ	38	FREE
18	618-626MHZ	39	OCCUPIED
19	626-634MHZ	40	FREE
20	642-650MHZ	42	OCCUPIED
21	650-658MHZ	43	FREE
22	658-666MHZ	44	OCCUPIED
23	666-674MHZ	45	OCCUPIED
24	674-682MHZ	46	OCCUPIED
25	682-690MHZ	47	OCCUPIED

Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	DO_NOT_ALLOCATE
2	482-490MHZ	22	OCCUPIED	NO_ACTION
3	490-498MHZ	23	OCCUPIED	DO_NOT_ALLOCATE
4	498-506MHZ	24	OCCUPIED	NO_ACTION
5	506-514MHZ	25	FREE	DO_NOT_ALLOCATE
6	514-522MHZ	26	FREE	NO_ACTION
7	522-530MHZ	27	FREE	ALLOCATE
8	530-538MHZ	28	FREE	NO_ACTION
9	538-546MHZ	29	FREE	ALLOCATE
10	546-554MHZ	30	FREE	NO_ACTION
11	554-562MHZ	31	OCCUPIED	DO_NOT_ALLOCATE
12	562-570MHZ	32	OCCUPIED	NO_ACTION
13	570-578MHZ	33	OCCUPIED	DO_NOT_ALLOCATE
14	578-586MHZ	34	FREE	NO_ACTION
15	586-594MHZ	35	OCCUPIED	DO_NOT_ALLOCATE
16	594-602MHZ	36	FREE	NO_ACTION
17	602-610MHZ	37	OCCUPIED	DO_NOT_ALLOCATE
18	610-618MHZ	38	FREE	NO_ACTION
19	618-626MHZ	39	OCCUPIED	DO_NOT_ALLOCATE
20	626-634MHZ	40	FREE	NO_ACTION
21	634-642MHZ	41	FREE	DO_NOT_ALLOCATE
22	642-650MHZ	42	OCCUPIED	NO_ACTION
23	650-658MHZ	43	FREE	DO_NOT_ALLOCATE
24	658-666MHZ	44	OCCUPIED	NO_ACTION
25	666-674MHZ	45	OCCUPIED	DO_NOT_ALLOCATE

Ubulu Uku result 2

TV WHITE SPACE OPTIMIZATION USING GENETIC ALGORITHM

HOME GA CONSOLE GRAPHS TABLES LOG OUT

Current Location:UBULU-UKWU

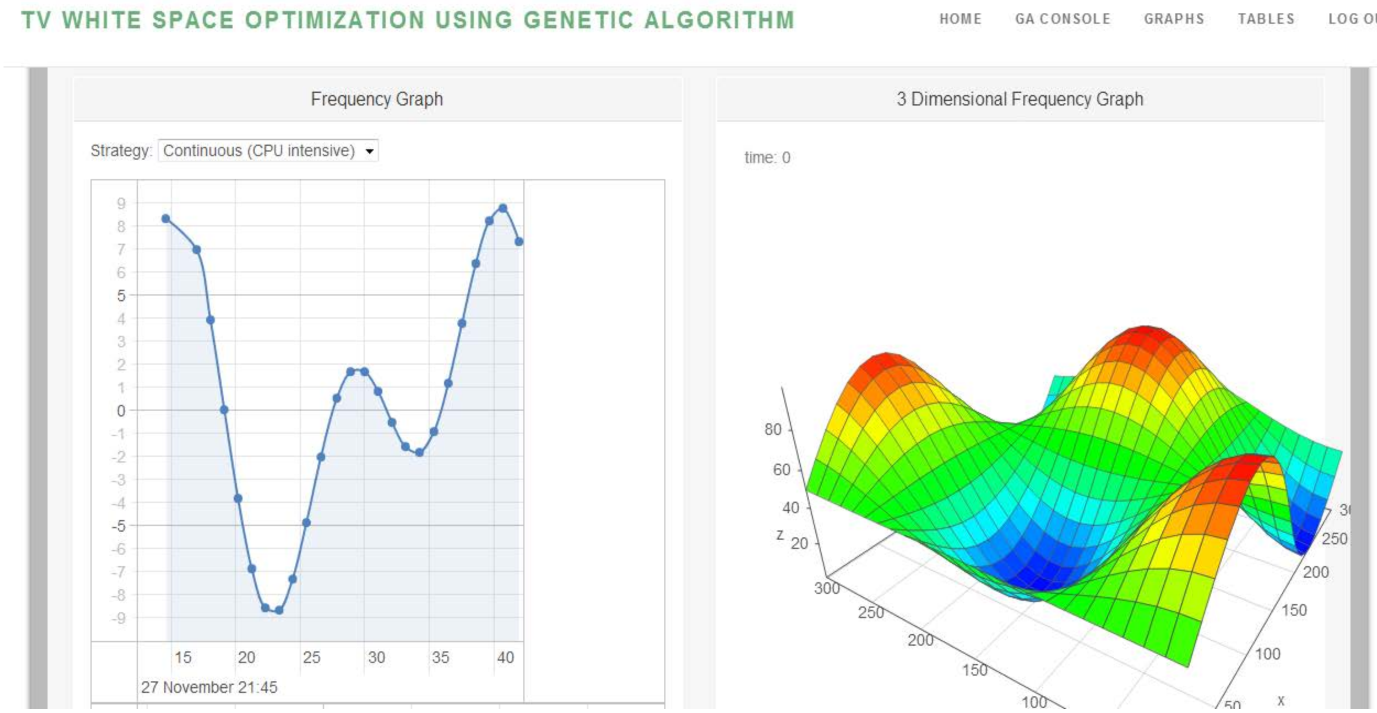
Available Channels Table

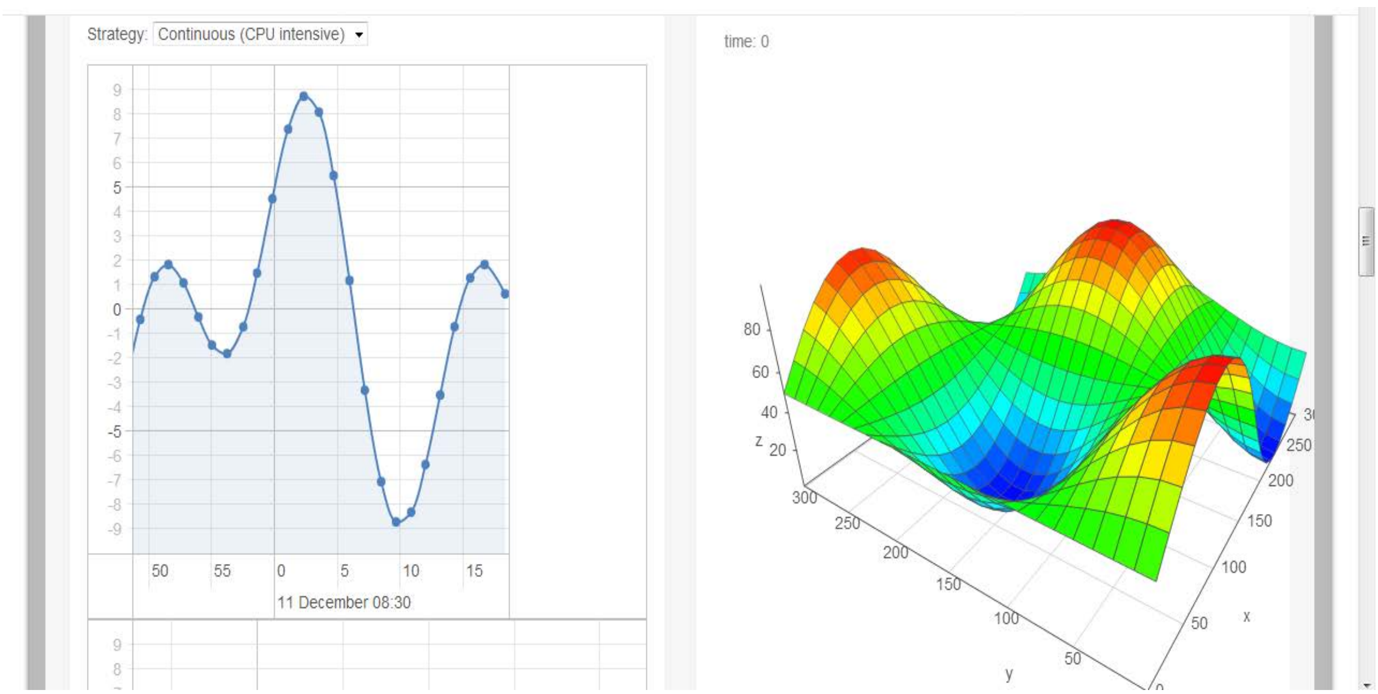
SN	Band	Channel No	Status
1	482-490MHZ	22	OCCUPIED
2	490-498MHZ	23	OCCUPIED
3	498-506MHZ	24	OCCUPIED
4	506-514MHZ	25	FREE
5	514-522MHZ	26	FREE
6	522-530MHZ	27	FREE
7	530-538MHZ	28	FREE
8	538-546MHZ	29	FREE
9	546-554MHZ	30	FREE
11	562-570MHZ	32	OCCUPIED
12	570-578MHZ	33	OCCUPIED
13	578-586MHZ	34	FREE
14	586-594MHZ	35	OCCUPIED
15	594-602MHZ	36	FREE
16	602-610MHZ	37	OCCUPIED
17	610-618MHZ	38	FREE
18	618-626MHZ	39	OCCUPIED
19	626-634MHZ	40	FREE
20	642-650MHZ	42	OCCUPIED
21	650-658MHZ	43	FREE
22	658-666MHZ	44	OCCUPIED
23	666-674MHZ	45	OCCUPIED
24	674-682MHZ	46	OCCUPIED
25	682-690MHZ	47	OCCUPIED

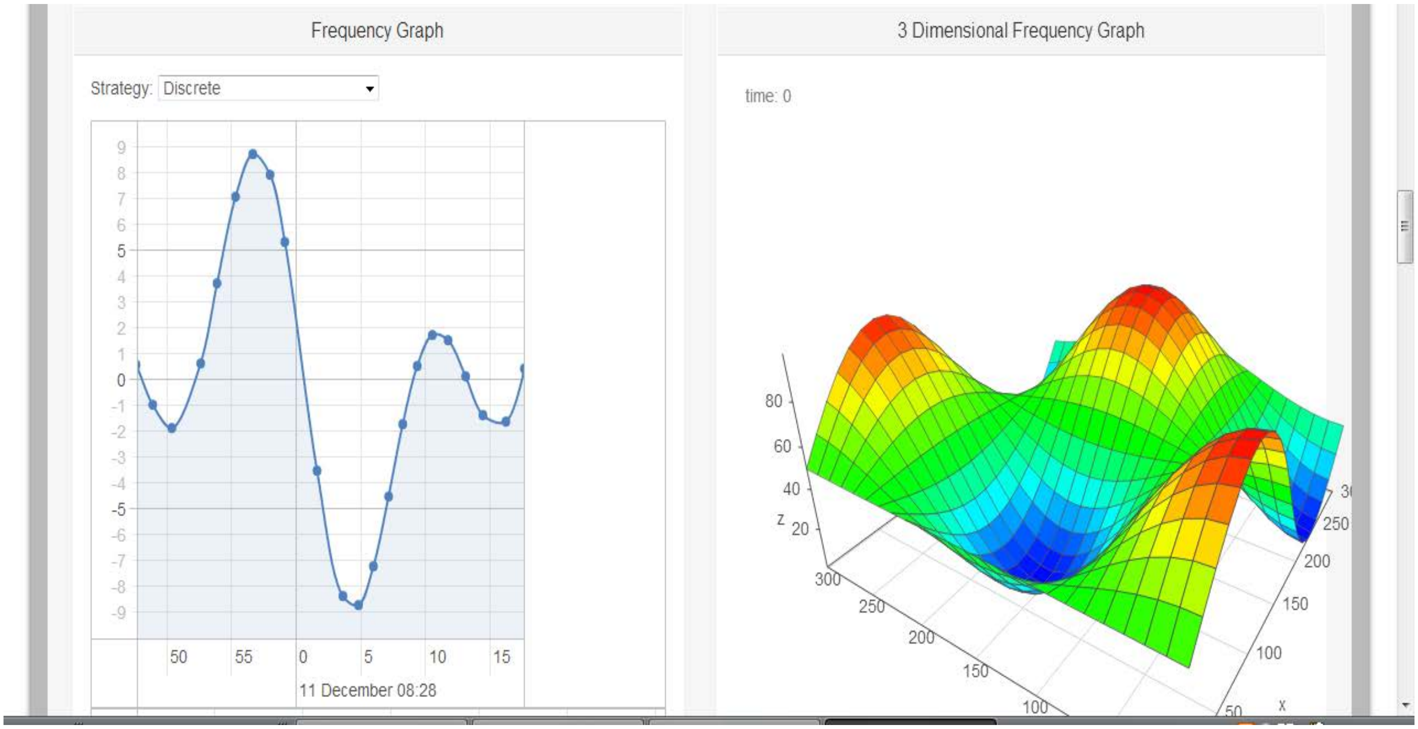
Channel Allocation Optimization Table

SN	Band	Channel No	Status	Action
1	474-482MHZ	21	OCCUPIED	NO_ACTION
2	482-490MHZ	22	OCCUPIED	DO_NOT_ALLOCATE
3	490-498MHZ	23	OCCUPIED	NO_ACTION
4	498-506MHZ	24	OCCUPIED	DO_NOT_ALLOCATE
5	506-514MHZ	25	FREE	NO_ACTION
6	514-522MHZ	26	FREE	ALLOCATE
7	522-530MHZ	27	FREE	NO_ACTION
8	530-538MHZ	28	FREE	ALLOCATE
9	538-546MHZ	29	FREE	NO_ACTION
11	554-562MHZ	31	OCCUPIED	NO_ACTION
12	562-570MHZ	32	OCCUPIED	DO_NOT_ALLOCATE
13	570-578MHZ	33	OCCUPIED	NO_ACTION
14	578-586MHZ	34	FREE	DO_NOT_ALLOCATE
15	586-594MHZ	35	OCCUPIED	NO_ACTION
16	594-602MHZ	36	FREE	DO_NOT_ALLOCATE
17	602-610MHZ	37	OCCUPIED	NO_ACTION
18	610-618MHZ	38	FREE	DO_NOT_ALLOCATE
19	618-626MHZ	39	OCCUPIED	NO_ACTION
20	626-634MHZ	40	FREE	DO_NOT_ALLOCATE
21	634-642MHZ	41	FREE	NO_ACTION
22	642-650MHZ	42	OCCUPIED	DO_NOT_ALLOCATE
23	650-658MHZ	43	FREE	NO_ACTION
24	658-666MHZ	44	OCCUPIED	DO_NOT_ALLOCATE

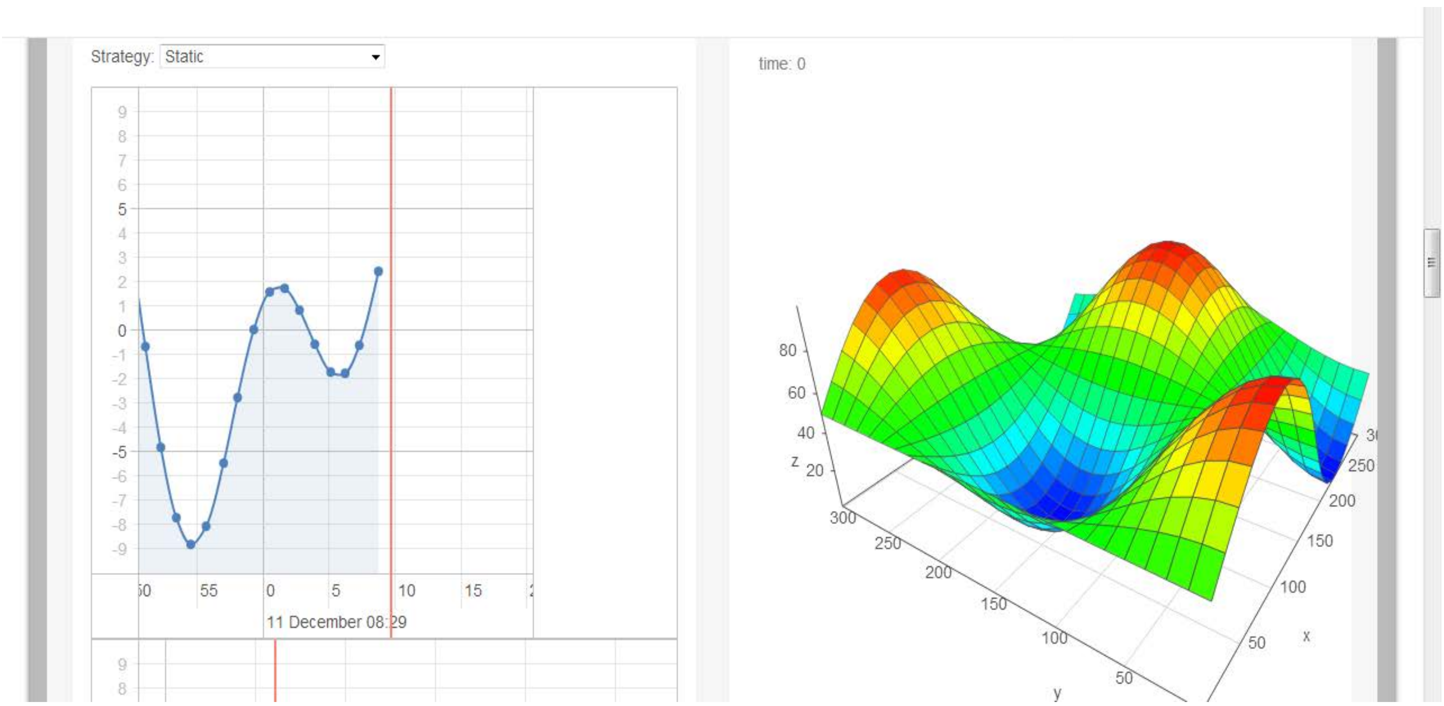
APPENDIX III (Frequency Scanning Outputs)







Frequency Graph
3 Dimensional Frequency Graph
Strategy: Discrete
time: 0
11 December 08:28



Strategy: Static
time: 0
11 December 08:29

APPENDIX IV (The rules for the rule based system)

1) If channel is available and channel is free and channel is occupied and channel is neighbour and signal strength is high then No allocation
2) If channel is available and channel is free and channel is occupied and channel is not neighbour and signal strength is high then No allocation
3) If channel is available and channel is free and channel is not occupied and channel is neighbour and signal strength is high then No allocation
4) If channel is available and channel is free and channel is not occupied and channel is not neighbour and signal strength is high then allocate
5) If channel is available and channel is not free and channel is occupied and channel is neighbour and signal strength is high then No allocation
6) If channel is available and channel is not free and channel is occupied and channel is not neighbour and signal strength is high then No allocation
7) If channel is available and channel is not free and channel is not occupied and channel is not neighbour and signal strength is high then No allocation
8) If channel is available and channel is not free and channel is not occupied and channel is not neighbour and signal strength is high then No allocation
9) If channel is available and channel is free and channel is occupied and channel is neighbour and signal strength is moderate then No allocation
10) If channel is available and channel is free and channel is occupied and channel is not neighbour and signal strength is moderate then No allocation
11) If channel is available and channel is free and channel is not occupied and channel is neighbour and signal strength is moderate then No allocation
12) If channel is available and channel is free and channel is not occupied and channel is not neighbour and signal strength is moderate then allocate
13) If channel is available and channel is free and channel is occupied and channel is neighbour and signal strength is moderate then No allocation
14) If channel is available and channel is not free and channel is occupied and channel is not neighbour and signal strength is moderate then No allocation

15) If channel is available and channel is not free and channel is not occupied and channel is neighbour and signal strength is moderate then No allocation
16) If channel is available and channel is not free and channel is not occupied and channel is not neighbour and signal strength is moderate then No allocation
17) If channel is available and channel is free and channel is occupied and channel is neighbour and signal strength is low then No allocation
18) If channel is available and channel is free and channel is not occupied and channel is neighbour and signal strength is low then No allocation
19) If channel is available and channel is free and channel is not occupied and channel is neighbour and signal strength is low then allocate
20) If channel is available and channel is free and channel is not occupied and channel is not neighbour and signal strength is low then No allocation
21) If channel is available and channel is not free and channel is occupied and channel is neighbour and signal strength is low then No allocation
22) If channel is available and channel is not free and channel is occupied and channel is not neighbour and signal strength is low then No allocation
23) If channel is available and channel is not free and channel is not occupied and channel is neighbour and signal strength is low then No allocation
24) If channel is available and channel is not free and channel is not occupied and channel is not neighbour and signal strength is low then No allocation

APPENDIX V (Analyzed TV White Spaces in different Locations)

Asaba and Environs

Frequency Span	Channel No	Status
474 – 482MHz	21	Occupied/in use
482 – 490MHz	22	Occupied/in use
490 – 498MHz	23	Occupied/in use
498 – 506MHz	24	Occupied/in use
506 – 514MHz	25	Free
514 – 522MHz	26	Free
522 – 530MHz	27	Free
530 – 538MHz	28	Free
538 – 546MHz	29	Free
546 – 554MHz	30	Free
554 – 562MHz	31	Free
562 – 570MHz	32	Occupied/in use
570 – 578MHz	33	Free
578 – 586MHz	34	Free
586 – 594MHz	35	Free
594 – 602MHz	36	Free
602 – 610MHz	37	Occupied/in use
610 – 618MHz	38	Free
618 – 626MHz	39	Occupied/in use
626 – 634MHz	40	Free
634 – 642MHz	41	Free
642 – 650MHz	42	Free
650 – 658MHz	43	Free
658 – 666MHz	44	Free
666 – 674MHz	45	Occupied/in use
674 – 682MHz	46	Occupied/in use
682 – 690MHz	47	Occupied/in use
690 – 698MHz	48	Occupied/in use
698 – 706MHz	49	Occupied/in use
706 – 714MHz	50	Free
714 – 722MHz	51	Occupied/in use
722 – 730MHz	52	Reserved
730 – 738MHz	53	Reserved
738 – 748MHz	54	Occupied/in use
746 – 754MHz	55	Occupied/in use
754 – 762MHz	56	Occupied/in use
762 – 770MHz	57	Occupied/in use
770 – 778MHz	58	Occupied/in use
778 – 786MHz	59	Reserved
786 – 794MHz	60	Reserved
794 – 802MHz	61	Free
802 – 810MHz	62	Free
810 – 818MHz	63	Free
818 – 826MHz	64	Free
826 – 834MHz	65	Free
834 – 842MHz	66	Free
842 – 850MHz	67	Free
850 – 858MHz	68	Free
858 – 866MHz	69	Free
866 – 874MHz	70	free

Awka and Environs

Frequency Span	Channel No	Status
474 – 482MHz	21	Occupied/in use
482 – 490MHz	22	Occupied/in use
490 – 498MHz	23	Free
498 – 506MHz	24	Free
506 – 514MHz	25	Free
514 – 522MHz	26	Free
522 – 530MHz	27	Free
530 – 538MHz	28	Free
538 – 546MHz	29	Free
546 – 554MHz	30	Free
554 – 562MHz	31	Free
562 – 570MHz	32	free
570 – 578MHz	33	Free
578 – 586MHz	34	Free
586 – 594MHz	35	Free
594 – 602MHz	36	Free
602 – 610MHz	37	free
610 – 618MHz	38	Free
618 – 626MHz	39	Free
626 – 634MHz	40	Free
634 – 642MHz	41	Free
642 – 650MHz	42	Free
650 – 658MHz	43	Free
658 – 666MHz	44	Free
666 – 674MHz	45	Free
674 – 682MHz	46	Free
682 – 690MHz	47	Free
690 – 698MHz	48	Free
698 – 706MHz	49	Free
706 – 714MHz	50	Free
714 – 722MHz	51	Free
722 – 730MHz	52	Reserved
730 – 738MHz	53	Reserved
738 – 748MHz	54	Free
746 – 754MHz	55	Occupied/in use
754 – 762MHz	56	Occupied/in use
762 – 770MHz	57	Occupied/in use
770 – 778MHz	58	free
778 – 786MHz	59	Reserved
786 – 794MHz	60	Reserved
794 – 802MHz	61	Free
802 – 810MHz	62	Free
810 – 818MHz	63	Free
818 – 826MHz	64	Free
826 – 834MHz	65	Free
834 – 842MHz	66	Free
842 – 850MHz	67	Free
850 – 858MHz	68	Free
858 – 866MHz	69	Free
866 – 874MHz	70	free

Nkpor and Envrons

Frequency span	Channel No	Status
474 – 482MHz	21	Free
482 – 490MHz	22	Free
490 – 498MHz	23	Free
498 – 506MHz	24	Occupied/in use
506 – 514MHz	25	Free
514 – 522MHz	26	Free
522 – 530MHz	27	Free
530 – 538MHz	28	Free
538 – 546MHz	29	Free
546 – 554MHz	30	Free
554 – 562MHz	31	Free
562 – 570MHz	32	Occupied/ in use
570 – 578MHz	33	Free
578 – 586MHz	34	Free
586 – 594MHz	35	Free
594 – 602MHz	36	Free
602 – 610MHz	37	free
610 – 618MHz	38	Free
618 – 626MHz	39	Occupied/ in use
626 – 634MHz	40	Free
634 – 642MHz	41	Free
642 – 650MHz	42	Free
650 – 658MHz	43	Free
658 – 666MHz	44	Free
666 – 674MHz	45	free
674 – 682MHz	46	Occupied/ in use
682 – 690MHz	47	Free
690 – 698MHz	48	Occupied/ in use
698 – 706MHz	49	Occupied/ in use
706 – 714MHz	50	Occupied/ in use
714 – 722MHz	51	Free
722 – 730MHz	52	Reserved
730 – 738MHz	53	Reserved
738 – 748MHz	54	Free
746 – 754MHz	55	Free
754 – 762MHz	56	Free
762 – 770MHz	57	Free
770 – 778MHz	58	free
778 – 786MHz	59	Reserved
786 – 794MHz	60	Reserved
794 – 802MHz	61	Free
802 – 810MHz	62	Free
810 – 818MHz	63	Free
818 – 826MHz	64	Free
826 – 834MHz	65	Free
834 – 842MHz	66	Free
842 – 850MHz	67	Free
850 – 858MHz	68	Free
858 – 866MHz	69	Free
866 – 874MHz	70	free

Ubulu-Uku and Environs (Delta State)

Frequency Span	Channel No	Status
474 – 482MHz	21	Occupied/in use
482 – 490MHz	22	Occupied/in use
490 – 498MHz	23	Occupied/in use
498 – 506MHz	24	Occupied/in use
506 – 514MHz	25	Free
514 – 522MHz	26	Free
522 – 530MHz	27	Free
530 – 538MHz	28	Free
538 – 546MHz	29	Free
546 – 554MHz	30	Free
554 – 562MHz	31	Occupied/in use
562 – 570MHz	32	Occupied/in use
570 – 578MHz	33	Occupied/in use
578 – 586MHz	34	Free
586 – 594MHz	35	Occupied/in use
594 – 602MHz	36	Free
602 – 610MHz	37	Occupied/in use
610 – 618MHz	38	Free
618 – 626MHz	39	Occupied/in use
626 – 634MHz	40	Free
634 – 642MHz	41	Free
642 – 650MHz	42	Occupied/in use
650 – 658MHz	43	Free
658 – 666MHz	44	Occupied/in use
666 – 674MHz	45	Occupied/in use
674 – 682MHz	46	Occupied/in use
682 – 690MHz	47	Occupied/in use
690 – 698MHz	48	Occupied/in use
698 – 706MHz	49	Occupied/in use
706 – 714MHz	50	Free
714 – 722MHz	51	Occupied/in use
722 – 730MHz	52	Occupied/in use
730 – 738MHz	53	Reserved
738 – 748MHz	54	Free
746 – 754MHz	55	Occupied/in use
754 – 762MHz	56	Free
762 – 770MHz	57	Occupied/in use
770 – 778MHz	58	Occupied/in use
778 – 786MHz	59	Reserved
786 – 794MHz	60	Reserved
794 – 802MHz	61	Free
802 – 810MHz	62	Free
810 – 818MHz	63	Free
818 – 826MHz	64	Free
826 – 834MHz	65	Free
834 – 842MHz	66	Free
842 – 850MHz	67	Free
850 – 858MHz	68	Free
858 – 866MHz	69	Free
866 – 874MHz	70	free