A TOOL FOR DETECTING AND DISTRIBUTING TV WHITE SPACES FOR COMMERCIAL PURPOSES

BY

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A RESEARCH PROJECT SUBMITTED IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF SCIENCE IN DATA COMMUNICATIONS IN THE FACULTY OF COMPUTING AND INFORMATION MANAGEMENT AT KCA UNIVERSITY

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MASTER OF SCIENCE IN DATA COMMUNICATIONS

2017

DECLARATION

I declare that this dissertation is my original work and has not been previously published or submitted elsewhere for award of a degree. I also declare that this dissertation contains no material written or published by other people except where due reference is made and author duly acknowledged.

NAME: TINGA A. MATANO Reg. No: **14/02506**

Sign…… Date ……

I do hereby confirm that I have examined the master's dissertation of

TINGA A. MATANO

And have certified that all revisions that the dissertation panel and examiners recommended have been adequately addressed.

Sign …… Date ……..

PROF. PATRICK OGAO

Dissertation Supervisor

DEDICATION

I would like to dedicate this thesis to my Mom, Alice Tabu Tinga and my siblings Stanley Tinga, Eileen Nazi and Hannington Mwangudza. Lastly but no to least to my beloved wife Caroline one time we will stand together again.

ACKNOWLEDGEMENT

I would like first to extend my sincere gratitude to my supervisors Prof. Ogao and Peter Maina for their unwavering and tireless supervision of this work. They combed through every bit of this research.

I wish to thank my family that through their support and understanding was the strength that kept me going on.

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Special thanks also go to Peter Maina for the assistance given during this research exercise. He was very instrumental in reviews and corrections made in the research report. I would like also to offer special gratitude to my friend David Kanyi who encouraged me through this period may God bless you and Trusila Monyenye of NITA who always gave me support jobs to finance my education. My brother Kai Tinga who was an encouragement for me to have a master's degree

Finally yet importantly, I would like to acknowledge the support and constant encouragement accorded by my fellow classmates. Your unreserved disclosure of information during benchmarking exercise cannot go unmentioned.

To all who I may not be able to mention by name here, but assisted during this research, I say thank you for your contribution in one way or the other. Last and foremost would like to thank the Almighty GOD to enable me to finish the project.

ABSTRACT

This document contains the results of the research study entitled in:-

Chapter one contains the title of the project, the background information, the problem statement and the source of the problem. A description of the general objective, the aim of the study, a brief description of the Specific objectives of the study guided by the following objectives investigation of the techniques and the legal constraints involved. Also documented is the significance of study that involves studies to ways to reduce the spectrum congestion. Last on this chapter is the scope of the study that contains the assessment, location and distribution of TV white space availability. In chapter two, the literature review came under discussion based on the following topics, electromagnetic spectrum and its allocation by international bodies. A description the TV white space and the methods involved in the identification of the spaces, the spectrum sensing techniques and the legal constraints involved. Chapter 3 involves research methodology that is the way the research was conducted and the methods used. Under the chosen method that is the experimental, the tools and the way the research experiment was set up. Chapter Four covers the conceptual design of the project it includes the introduction, its advantages and disadvantages. In this project, the conceptual models involved are the models of the database sensing model of the spectrum, a model of TVSW calculation tool and final a flow chart of the description of the working of the sensing device. Chapter 5 shows the test involved in carrying the modeling experiments. Mostly covered are modeling setups that determine the various variables of the wireless network under test and lastly the results obtained and their tabulations. Lastly, chapter six gives the conclusion of the work that was carried in this project and the recommendations to be taken for future work to bring an improvement to this project.

Key Terms: TV white space, tool and simulation

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ACRONYMS AND ABBREVIATIONS

FCC	Federal Communication Commission
AM	Amplitude Modulation
FM	Frequency Modulation
PM	Phase Modulation
ATSC	Automatic Transmission Suppressed Carrier
ADC	Analogue to Digital Coveter
DSA	Digital Signal Analyzer
SNI	Signal to Noise Interference
IEEE	Institute of Electrical and Electronic Engineers
DTT	Digital Terrestrial Television
PMSE	Programme Making and Special Events
WSD	Wireless sensing Devices
TVWS	Television White Space
UHF	Ultra High Frequency
VHF	Very High Frequency
WSDB	Wireless Sensing Database
WI-FI	Wireless Fidelity
WSD	Wireless Sensing Device
ATDI	Automatic Transmission Direction Identification
IBSS	Independent Basic Service Set
CR	Cognitive Radio
BS	Base Station
IEEE	Institute of Electrical and Electronic Engineers
SIR	Signal to Interference Ratio
ATR	Anti Transmit Receiver
RF	Radio Frequency
IF	Intermediate Frequency
ADC	Analogue to Digital Converter
LPF	Low Pass Filter
HPF	High Pass Filter
BPF	Band Pass Filter

LSB	Least Significant Bit
MSB	Most Significant Bit
GPS	General Position Sensor
DAC	Digital to Analogue Converter
FET	Field Effect Transistor
IGFET	Insulated Gate Field Effect Transistor
BPSK	Binary Pulse Shift Keying
QPSK	Quadrature Pulse Shift Keying
ITU	International Telecommunication Union

CHAPTER ONE

1.0 INTRODUCTION

TV white spaces are areas on the electromagnetic spectrum, left unused in a particular location at a given time in the spectrum. Radio spectrum is part of the electromagnetic spectrum thatis described as the range of frequencies or wavelengths that are arranged in order in terms of frequencies from low frequencies to high frequencies. The electromagnetic spectrum covers from the visible to the invisible spectrum. The visible spectrum is bounded between the low and the higher frequencies in the spectrum with the higher frequencies becoming hazardous and dangerous to human health. The application of such waves is in areas like medicine for the treatment of cancer and other growth problem, photographic examination of internal framework of both man and animals to detect fractured bones using x-rays. Casting and examination of formation of joints require higher frequencies and thus the use of gamma for the application of higher frequencies.

On the other hand, the low frequencies in the spectrum are less harmful and whichcan be harnessed and utilized for domestic applications, these frequencies ranges from the infrared, microwaves to radio frequency waves that are of particular interest to the study. Out of these three bands of frequencies, the radio frequencies have special characteristics of being able to ride on antennae.

Antennae's that are made of metallic materials of different sizes and shapes and made of different wavelengths are able to trap these frequencies. These frequencies are used for data transmission using modulation techniques through mobile phones, television sets, and radio and armature radios through wireless communication.

The advantages of radio waves over the other waves are that the radio frequency waves are able to carry information through the variation of their parameters such as phase, frequency and amplitude. The travelling waves when intercepted by an antenna always induce an electron motive force on the surface of the antenna by exiting electrons of the antenna.

Since almost all the transmission of data, information and news uses a specific part of the spectrum, most nations of the world have come up with regulations to regulate this part of the

spectrum through frequency allocation. This has been met with the challenges that most of the day-to-day communication devices are wireless in both scientific and social world. These gadgets compete for the radio frequency spectrum, which has become a scarce resource and therefore other means of transmission and reception are required to save the situation. The use of other means to access the spectrum other than the one permitted is referred to as secondary access and one method is to use the television white spaces devices to solve the problem of spectrum scarcity, which is the basis of this project.

1.1Background of the Problem

The global mobile traffic is growing at a higher rate, that various organizations and technical companies have viewed this growth to be tremendous within the next decade. The growth of the mobiles devices goes with the growth in demand of the data traffic and hence the demand of more channel allocation from the spectrum as demanded by the mobile communication devices.

Globally, there are selected bodies specifically for the management of the spectrum at the global level, one of these main bodies is the federal communication commission that has the right to manage the spectrum global and issue fair distribution of the channels along the continent. The mandate to control regulates, and issue permits to the primary spectrum users lies under to this body. In their allocation, there are several areas left empty as gaps and referred to as guard bands and their main purpose is to protect the primary user from interference.

This guard bands contain low frequencies that can be harness and used for mobile communication since they are user friendly to wireless communication. The guard band frequencies appear as gaps in the spectrum and that is why the name white space came is applied. The white spaces have a characteristic of supporting wireless communication and thus the name super WI-FI.

The introduction of any other user in the spectrum demand extra space in the spectrum and needs the regulatory authorities to relax their muscles on the regulation of the spectrum and also monitor the allowed secondary not to cause any harmful interference to the primary user.

Therefore, to extend the mobile communication the secondary user has to come into play and since there is the white space, several conditions on the regulatory system need to be modification to allow the expansion of the spectrum to accommodate this problem of wireless shortage.

Sensing and distributing of the spectrum is a sensitive issues in the world since it involves sensitive matters such as security of a country and may also interfere with the navigation of vessels for both marine and aircrafts to name a few. Therefore, to access the spectrum several problems have to be looked into which involves_

1) Allow frequency regulatory bodies to change their way of allocating frequencies
2) Specially method of sensing and monitoring the spectrum and the use of information data bases can be used to lessen the problem of interference
3) Devices put into the system should be able to share and communicate with each and the databases.

The research wishes to solve problem two and three because both of them concern interference with the primary user. Therefore the project will describe a device that can built and be able to go into the spectrum and sense and monitor the spectrum without causing harmful interference, and with the use of simulating soft ware tool the performance of the device can be demonstrated.

The results of this study will be important to

i) White space will extend the bandwidth of the wireless communication and thus decongest the spectrum
ii) The characteristics of the white space to ride on other transmitted signals, makes it viable to harness from other source and this idea used by wireless technologies can operate in some areas considered uneconomically by major service providers.
iii) Since these white spaces have shown the capability of extending the bandwidth, a means of accessing and utilizing this space is required without causing interference to the legal customer. iv) This can be done by developing a device that will go into the system without causing interference and at the same time without breaking the set protocols by the regulatory authorities and be able to sense and extend the frequency
iv) Policy makers will have to adjust the system of frequency allocation to accommodate more stakeholders to use the spectrum effectively.
v) To the academia the project will benefit them as a source of reference materials when carrying research projects

1.2Problem Statement

The frequencies allocated for wireless devices ranges from 700MHz to 2.6GHz, these frequency spectrum is too small for the already existing devices for radio frequency wireless communicating devices. As from analysis, the smart phone uses a bandwidth of 24 times as compared to the analogue phone and the tablet uses the same bandwidth one hundred and twenty two times. (Condon J. J., 2002) To compound on the problem most of the spectrum has already been licensed to government agencies, wireless carriers and TV broadcasters leaving users with almost nothing to use and as a result developing a stiff competition to all spectrum users.

Some of the remedies that to taken to ease the problem of spectrum congestion could be:

i) regulating agencies having to work with other regulating agencies work on a certain band of frequencies and free the other allocated frequencies to commercial users.

ii) Developing incentive programs, which would motivate TV broadcasters to allow the underutilized or unused frequency spectrum for sale that they can free the spectrum to other users.

iii) regulating agencies can also come up with changes in rules and regulations and also allow those frequencies band in the radio frequency spectrum that are not utilized to their allocated duty to pave way for others such as satellite communication to be used in conjunction with broadband mobiles services.

iv) The regulators can also look at the classic quandary regulators when they have auctioned the additional spectrum should they leave the market forces to dictate themselves out in the Darwinian sense of survival for the fittest where the strongest bidder is to get the spoils or they intercede to protect the weakest.

All these above solutions shows a slow process of freeing the spectrum as compared to the rapid growing rate of the mobile and Internet services over the wireless communication channels and hence other methods of coming up with alternative ways of transmitting wireless signals have to designed and TV white space being one of the alternatives.

1.3Definition of Terms

1) **White space –** These are unused frequencies of broadcasting in the televisionnultra high frequency (UHF) spectrum. Television broadcasting transmission has the ability to

compress and decompress their frequencies and thus leaves gaps. The gaps are also produced when allocating the TV channel for interference protection

2) **Wireless communication-** this is the delivery of data from one point to the other without a dedicated media such as a wire, the mode of transmission in such a case is through broadcasting with the use of wireless communication technologies such as a zigbee
3) **Availability–**This describes the time that a device is able to function under specified conditions without failure. It can be described as the reliability of the system to improve maintenance testing and diagnosis

1.4 ResearchObjectives

The general objective of the research is to develop a tool that can detect, analyze measure and distribute the amount of TV white space that is for use by the public as an alternative source of spectrum. Specifically the research sought to-

i) To identify the techniques used to locate the available white space that can be used to extend wireless mobile device usage.
ii) To establish the legal constraints that limits the usage of this spectrum.
iii) To design and develop a tool that would sense the empty space on the spectrum
iv) To evaluate the tool

1.5 Motivation of the Study

i) Concern about the scarcity of the spectrum that pose challenge in meeting the increasing demand for deployment of wireless communication devices.

ii) Today's typical mobile wireless devices occupy more than 80% of the spectrum occupied by wireless devices.

iii) Growth of mobile and Internet service usage is expected to drive for the increase of usage of the spectrum.

The current rate of spectrum demand cannot be sustained unless other methods and policy factors are adjusted to easy the demand.

1.6 The Scope of the Study

The system will cover the assessment and location and distribution of the TV space availability in dynamic spectrum to the general public.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introductions

This chapter involves the review of the electromagnetic spectrum, which is the study of the components of the spectrum. Also included is the review study of the detecting that is given as the information giving devices, beacons and cognitive radios. Sensing techniques and the legal constraints involved in spectrum detection and lastly the description of the equipment itself

2.2 Electromagnetic Spectrum

This is a range of a set of all types of electromagnetic radiations. The energy that travels, spread out, is referred to as radiation. The electromagnetic spectrum is composed of the following waves:

a)Radio-These radiations are generated by radio stations; gases and stars in the atmosphere also emit them. (Condon J. J., 2002)

b)Microwaves -These types of waves produced by the upper galaxies and used by the astronomers to study the structures of other nearby galaxies. They have a frequency range of about 3Hz. There wavelengths ranges from 1mm to 25 micrometer, these waves can also be generated by micro wave devices and system to heat food, and can also be used for communication in the microwave range. (Condon J. J., 2002)

c)Infra red-They are emitted by hot objects in the galaxies such as planets and stars, the range of frequencies for such wave's lies between $1 \times 10^{13} to\ 1 \times 10^{14}$Hz and their wavelength ranges between 25 nanometers to 75 nanometers. These waves can be viewed by the use of night vision goggles. The waves released in the atmosphere by the galaxies cannot penetrate to as far as into the atmosphere; carbon dioxide and water vapour in the atmosphere inhibit the waves emitted from reaching as far as the earth surface. (Ransom, 1997)

d)Visible spectrum-This is only a small part of the electromagnetic spectrum ranging from $4\times 10^{14} to\ 7.5 \times 10^{14}$ Hz in frequency and their wavelengths also varies in the range between 750 nanometers' to 400 nanometers. The visible spectrum is the one involved in day to day vision, it is not blocked even by the atmosphere although its light can be scattered by the clouds.

The visible spectrum is further be subdivided according to the colors of the rainbow with red at the lower level and violet at the upper level (Sadiku M. , Electromagetic field theory, 1997)

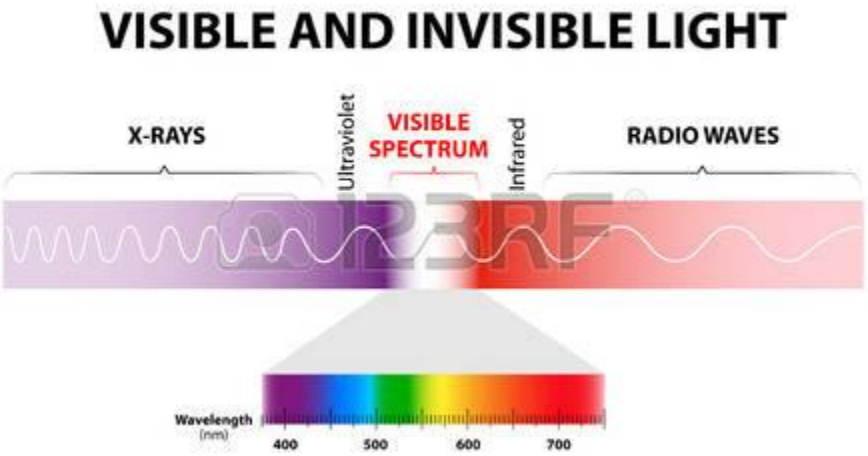

Figure 1: A diagram of the spectrum (Franklin R., 2006)

e)Ultra violet-These types of waves are emitted or produced by the sun and the stars. The waves are very destructive especially to the human skin. The waves vary in frequency between$10^{15}to10^{17}$Hz and the wavelength varies between 400nanameters to 1 nanometer. Hot objects in space also emit the waves; the radiations do not reach the earth space since they are absorbed by the ozone layer at the altitude above 30 kilometers.(Sadiku M. , Elements of electromagnetics, 1997)

f)X-rays-These are waves that are detected by fluorescent materials such as zinc sulphide. The range of frequency varies from $10^{17}to10^{20}$Hz and they have wavelengths of less than 10 meters. They are produced by the upper galaxies and are absorbed in the upper atmospheres by the ozone layer. The x-rays can be classified as short wavelengths hard x-rays and long wavelengths the soft x-rays. The x-rays generated artificially are used in security services as well as medical services.(Sadiku M. , Elements of electromagnetics, 1997)

g)Gamma rays-These are the last members of the group in the upper spectrum and posses the shortest wavelengths. Their frequencies range from $10^{20}to10^{24}$ Hz and their wavelengths is less than 10 meters. Produced by the upper galaxies and absorbed by the ozone layers. They find there use in magnetic resonance imaging in medical services.(Carson, 1970)

The above group of frequencies is natural arranged according to frequencies and wavelengths in a spectrum as shown in the figure below.

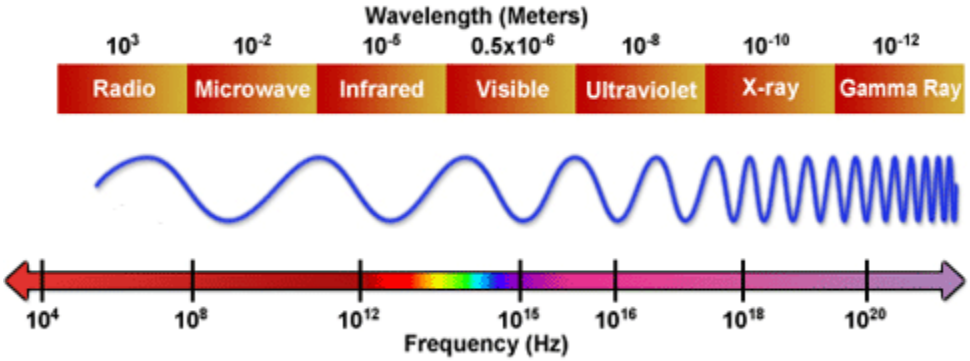

Figure 2: Spectrum frequencies and wavelength

The gaps that are left on the spectrum are known as the spectrum holes that can be considered to represent opportunities that are potential for safe (none interfering) utilization of t5he spectrum band it can also be considered like multidirectional areas within time, space and frequency. These spectrum holes, found within the radio frequency spectrum, are very useful to wireless system that delivers a real value to the people who use them.(Heinerman, 2003)

The utilization of a band of frequency by a system in the closeness of another system (a second) tuned in the same channel frequency will degrade the system performance of the other channel if the interference between the two channels is not checked. Due to the scarcity of the spectrum the spectrum, it is controlled across the planet, bands are only allocated for specific purposes, and quite often permits or licenses are issued for a particular band for this specific purpose.(Heinerman, 2003)

Due to these legal constraints, it is illegally to transmit in a certain channel without a legal permit. This has been the main source of avoiding interference in the spectrum but in practice, this happens in expenses of the utilization of the channel. A frequency band in the spectrum may be considered underutilized if it can be able to accommodate other transmission without interference and harming the main users (primary) band of frequency. They are of frequency- time- space in which a given particular secondary or another use is possible is what is called a spectrum hole.(FCC, Specrtum congestio, 1996)

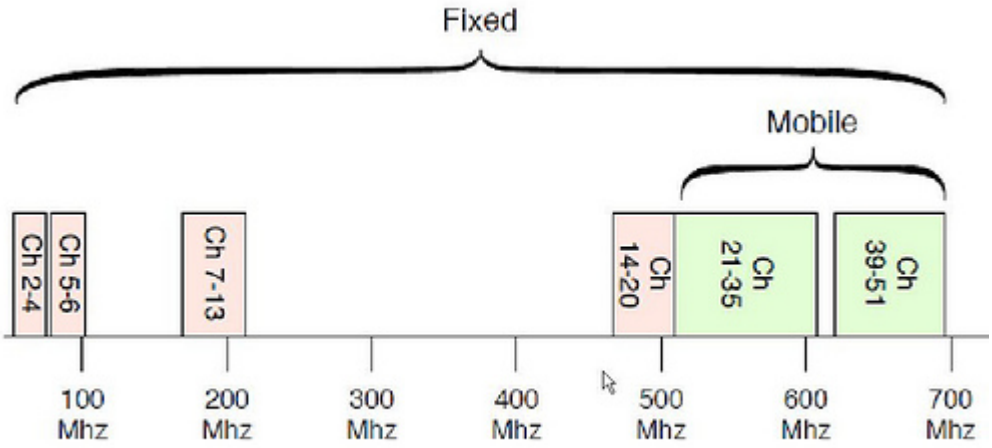

Figure 3: T.V white spaces spectrum in the united state (Boylesstand, 2013)

These spectrum holes in the TV bands of frequencies are called TV white spaces. Whatsoever we try to fill these gaps in the spectrum there will be spaces in the transmitted spectrum, which are made greater by the behavior of the transmitted TV waves which have the ability of expanding and compressing. Utilizing these gaps for secondary transmission can be variable especially for a dynamic spectrum.(Boylesstand, 2013)

Introducing right sensing methods to the spectrum and by the use of geo- position data locators to give a detail of the spectrum activity and a bit of spectrum relaxation of legal constraint, devices that have primitive cognitive radio abilities can be used to sense the spectrum without harmful interference. See the diagrams below

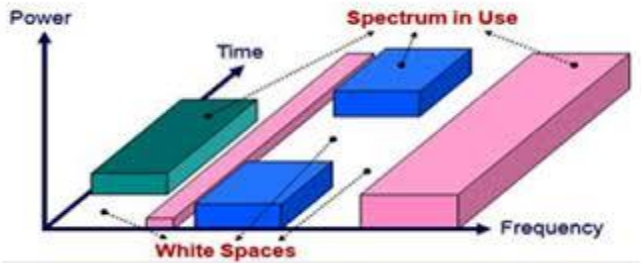

Figure 4: A diagram of TV white space (Finney, 1970)

2.3Spectrum Detecting Devices

The spectrum that is licensed is rarely used across space and time. The relatively low usage of this licensed frequency spectrum gives the suggestion that this scarcity as seen today is more or less due to un efficient fixed allocation of frequencies rather than the physical shortage of the frequency spectrum.(Condon J. J., 2002)

This observed problem has led to the regulatory authorities to carry a radical investigation of

Opportunistically use the unutilized primary bands that are licensed commonly called the TV white space in the bands of television transmission.

The federal communication commission (FCC) in particular has already shown its interest in letting unlicensed access to this white space found in the television bands. This particular interest stems in as a part of the great characteristics of propagation of the television frequency bands and their predictable relative spatiotemporal characteristic usage.(FCC, Specrtum congestio, 1996)

Based on this interest, bodies like IEEE have come in to form working groups or organizations to start to develop a medium of air interface to be used by opportunistic access by secondary users to the spectrum.(Finney, 1970)

In order to guard the primary utilizes from the adverse secondary user's effects of interference, the TV white spaces across, time, space and frequency have to be identified reliable. Some of the common identifying methods have been–

2.3.1 Information giving on Data Devices

One of the methods would be to make the primary systems in charge of providing the secondary systems with information on the usage of the spectrum. The primary would give data about its power usage and its power usage and identification by broadcasting the relevant information on beacons regionally or providing this information on database placed centrally where anybody with a need can access.(Boylesstand, 2013)

While the above methods lead to the use of secondary Transceivers, their main limitations would be:

i) The system has incompatible with the primary system hence require some modifications.
ii) Their deployment to the system is costly at the same time needs positioning information from the secondary system to add on to this a ubiquitous connection linked to a database or a dedicated channel to transmit to the beacons.

Another method is the use of spectrum sensing which uses the secondary systems or devices themselves to identify the white spaces through sensing the white spaces directly. In this format the device is kept to monitor the performance of a primary device and if an opportunity arises the secondary device transmits when it finds that there is no signal usage from the secondary.(Heinerman, 2003)

The advantage of this spectrum sensing method is that this system has:-

i) A cheap infrastructure cost
ii) It is compatible with the primary users.

The secondary device should have the ability to detect autonomously and at the same time to react with changes in the rate of spectrum usage, a technique, which enables the secondary device to poses some form of primitive cognitive radio properties, should be able to access a dynamic spectrum.(Mitola J. , Cognitive Radios making software, 1998)

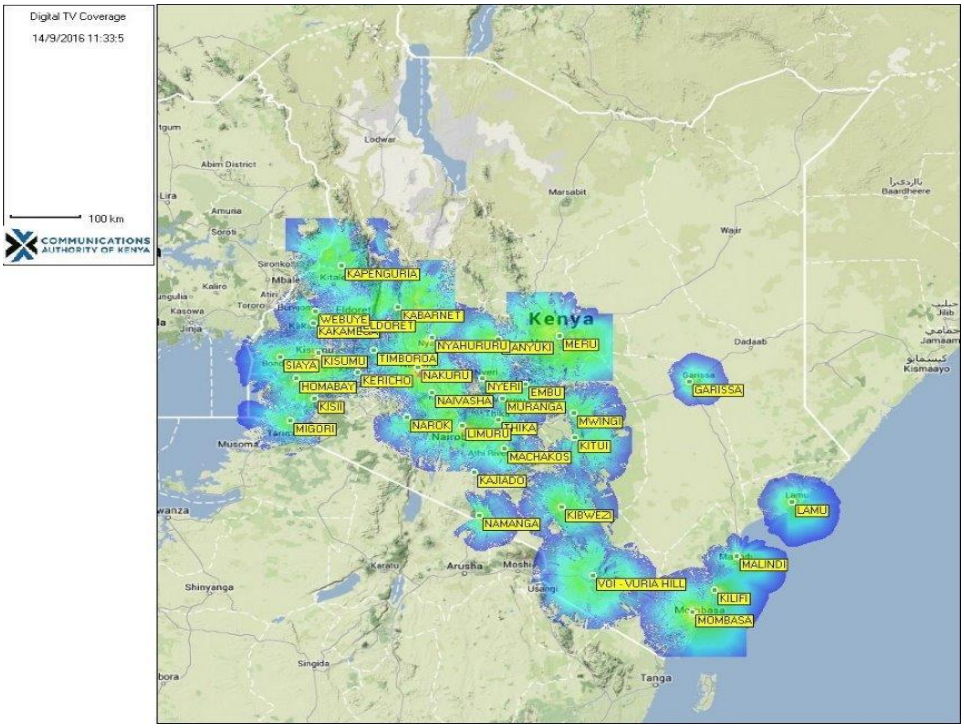

Figure 5: A map of sites of TV white space in Kenya (picture in courtesy of CCK)

The grey areas on the map show the available white spaces that can be used for the wireless communication.

In most cases data bases are separately built, the database for the protected area, data for the white spaces etc.

2.3.2 Cognitive Radio

This is a form of wireless communication device in which a Tran's receiver can intelligently detect which communication channels are in use and which are not instantly move into vacant channels while avoiding occupied ones. It has the ability of optimizing available radio frequency.(Mitola J. , Cognitive Radios making software, 1998)

The radio has some intelligence and it can be programmed, at the same time be configured dynamically, it is a transmitter's receiver radio designed to search and use the best remote wireless channels in its surrounding. The radio has the ability to detect automatically unused channels in the spectrum and then adjusts accordingly its reception or transmission parameters to permit more available concurrent communication in wireless systems in a given band of spectrum

at any one location. This process is a primitive form of dynamic spectrum management and assessment.(Condon J. J., 2002)

The operation of a cognitive system depends on the commands given by the operator and the set will automatically be able to set and configure these transmission parameters such as:

i) Protocol
ii) Waveform
iii) Networking
iv) Operating frequencies

This radio system is an autonomous functional unit in the communication surroundings, the radio will always process and give information concerning the surroundings of the network that it can penetrate and get access to and share and exchange the acquired information with other systems in its vicinity. The radio is able to monitor its own performance continuously and simultaneously reading and analyzing the outputs from units or systems and then utilize this necessary information for radio frequency environment assessment, determination, link performance conditions of the channels etc. and simultaneously adjusting automatically the setting parameters of the radio system to deliver services of quality that are needed subject to functional and operational limitations, carefully and appropriate mixing of regulator and user requirements constraints.(Boylesstand, 2013)

Cognitive radios can be grouped into two sections depending on transmission and reception parameters, these are:

Full cognitive radios whereby in these systems a wireless remote node observes and analyses each node of the network and the other is the spectrum sensing and analyzing cognitive radio where the system senses radio frequencies in the spectrum only.(Condon J. J., 2002)

Another approach of sensing using cognitive radios is the filling free radio frequency spectrum bands adaptively utilizing OFDMA that is a possible approach. This system proposes a method of spectrum pooling in which free spectrum bands (sensed by nodes) are immediately occupied by OFDMA side bands. The application of sensing spectrum using cognitive systems includes wide area network and emergency networks of higher throughput, and distance transmission extension. The evolution of this system i.e. the cognitive radio system towards networks that are cognitive is

underway. The principle of cognitive nodes is to have the ability to intelligently manage and organize a network system of cognitive radios.(Skurzynski, Electromagnetic fieds sensing, 1995)

2.4Sensing Techniques

One of the method of spectrum sensing would be the coherent detection approach whereby the structure of the signal in the primary device is known, the noise content is filtered and then signal content is tested this would give the signal strength of the primary user. The application of this method suffers from other impediments including cost implementation and complexity since the device will require dedicated internal circuitry to achieve the required synchronism with the kind of primary user as demanded for coherent detection method.(FCC, Specrtum congestio, 1996)

Another method for sensing the primary signal in a noise environment is to use energy detection method. The energy detector device measures the received energy in a primary band at the time declared as the observation internal and gives the information that a white space exists if the value of the measured energy is less than the set value of the primary energy bands.(Finney, 1970)

This method is mostly preferred than the first one since it is cheap and simple in implementation. The main disadvantage of this system is that it cannot be able to discriminate noise and the primary signal, making the method susceptible to noise power from the background at minimal signal to noise ratio.(Fisherman, 1994)

In most cases if a few features in the primary signal are, known such as modulation techniques and carrier frequency more advanced detectors can be employed to solve the problem of detection at the expense of increased cost due to the increase in complexity. This is due to most communication waves exhibit spectral correlation with their in built features like bit rate, carrier frequency etc. due to the fact that a spectral correlation features of different waves are usually unique, these properties permits detection by use of radios to detect specific signal buried in interference and noise. In normal circumstances a combination of methods are utilized in practice. The performance of a sensing device may be improved by sensing the spectrum for a longer period, however this is also limited by regulatory constraints.(Fisherman, 1994)

2.5Regulatory Constraints

The main objective of regulating sensing of the spectrum is to protect the primary system or user from harmful interference. Therefore, the performance sensitivity is guided by the following characteristics: -

2.5.1 Sensing Period

This is the period whereby the secondary user is an aware of the appearing of the primary system to cause harmful interference with the primary user. This determines the quality of services and the delay period therefore the sensing time for which depends on the primary system is normal set by the licensing body. Less spectrum, sensing is normal permitted for TV spectrum in which the spectrum utilization varies over a larger time scale. It is also noted that it is not possible to sense and transmit on a licensed channel simultaneously, because sensing must be interleaved with the transmission of data. To maximize the available time for transmission of data the sensing time is set below the set sensing period.(Boylesstand, 2013)

2.5.2 Detection Sensitivity

If the detector causes the signal to interference ratio (SIR) to fall below a certain given threshold as permitted by the regulatory body, then this is considered harmful to the primary user.

2.6Equipment Description

The equipment for sensing the white space must be a device that has the ability of sending and receiving electromagnetic waves. It should be a device with at least primitive cognitive radio features whereby it should be able to transmit, receive and identify itself where the device is placed in the network and be able to cope with the selection of a free band from a dynamic spectrum

Such an equipment should have a system of antennae's that can be able to transmit and receive electromagnetic wave, one of the properties such antennae's is the it should be able to radiate and receive equal in all directions that is an omni-directional antenna that is referred to as an isotropic antenna's.

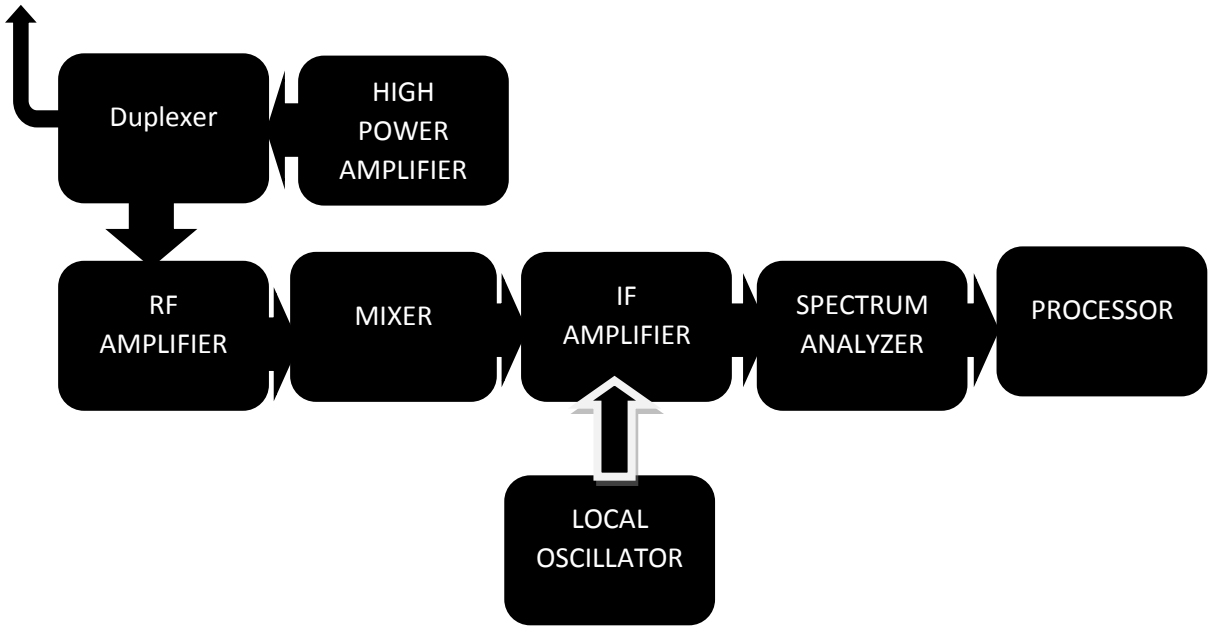

Figure 6: A block diagram of a sensing device

The antennae will be connected to a pre-selector circuit that can connect the antennae to the transmitter side when transmitting and to the receiver side when receiving such a circuit is known as the duplexer circuit.

2.6.1 The Duplexer Circuit

The duplexer is a switch the alternates between the two position of the transmitting and receiving mode of the device. The signal produced by the device travels through the transmitting antennae to the area that is being monitored and the signal from the monitored spectrum is received by the receiving mode of the device. The duplexer has two components: -

i) Transmit – Receiver (TR)- this is capable of protecting the delicate circuitry of the receiver shielding it from high powers generated during the transmission period.
ii) The Anti- Transmit Receiver abbreviated as the ATR this is capable of sending the received signal to the receiver and not to the transmitter.

This duplexer switch can be termed as a pre-selector switch as it allows the automatic selection of the antennae.

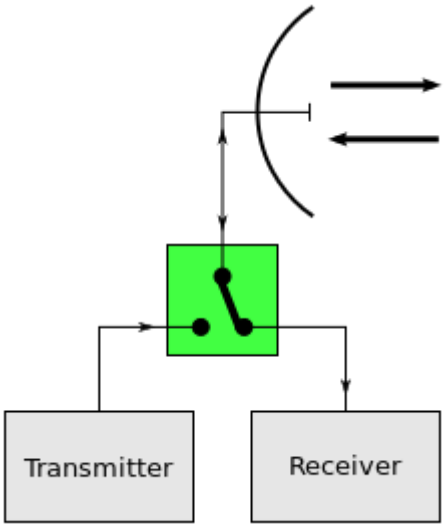

Figure 7: Duplexer circuit

2.6.2Higher Power Amplifier

An amplifier is an electrical or electronic device that can raise the level of a power signal. The work of an amplifier is to power from a power supply and then to control the output signal so components or digital circuits such as integrated circuits can design amplifiers.

In designing amplifiers, categories arise depending on the type of application it is going to be put under use, when frequency is used to design the amplifier it becomes known as an audio amplifier and this amplifier amplifies signals in the audio range. Radio frequency amplifiers (RF) modulate signals in the radio frequency range.

Classification of amplifiers by quantity comes with four types of amplifiers, which are, voltage or current amplifiers, trans-resistance and trans-conductance amplifiers. A further distinction of categorizing amplifiers depends on the relationship between the input and the output that brings about non- linearity and linearity amplifiers, further classification depends on the placement of the signal in the amplifier.

In power amplification and transmission of signals amplifiers are classified in terms of frequencies and classes, and in classes the classification is done according to circuit configuration and the method of operation used. These classes represent the quantity of the output signal that varies inside or within the amplifier over one cycle when an input signal excites the amplifier, with this type of classification amplifiers can be grouped into the following groups:-

i) Class A

ii) Class B

iii) Class C

iv) Class AB

These are defined in terms of their state of conduction over some portion of the output signal where the active device becomes “on or off.”

Class a amplifiers –the most popular type of amplifiers in the classification because of their simplicity in design, also called the best class because they have low signal levels of distortion. These type of amplifiers use the same single transistor either bipolar, FET or igfet connected in the common emitter configuration, for both halves of the input waveforms the active device will always have current flowing through the device.

This means that the active device is biased with the Q point in the middle of the load line and the active device will never be driven into cut off or saturation. This has the disadvantage that the transistor is not turned off.

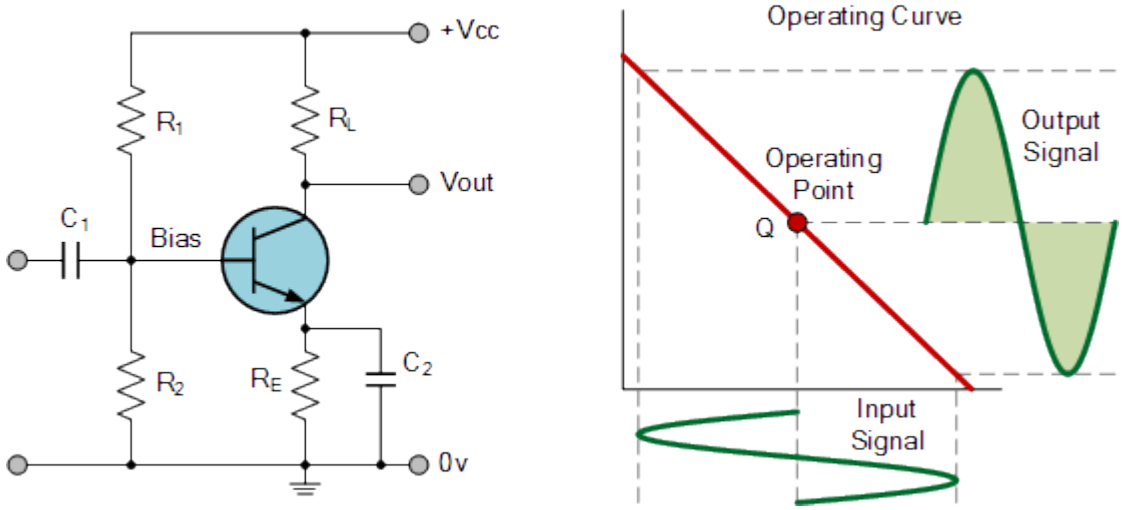

Figure 8: Class A amplifier and its operating characteristics (Genes P. , 1985)

To achieve high gain and linearity the active device of a class A amplifier is set own throughout the output. For amplifiers to be classified as class A amplifiers the zero or nil idle output current

stage must be greater or equal to the highest load current required to generate the largest signal output.

This amplifier operates in the linear region of the characteristics graph, the single out put amplifier is on throughout the cycle i.e. 360°of the output signal. Because of such requirements, the D.C biasing voltage of the device base should be carefully chosen to ensure low distortion and correct operation

The disadvantage of this type of amplifier is that it is on all the times and therefore there is a great power loss and creates large amounts of heat loss which makes them to have low efficiency of about 38%. This makes these amplifiers impractical for high power signal amplification.

Class B –the solution to large heat loss and lower efficiency was done by designing of class B amplifiers. The primary class B amplifier utilizes two complimentary active device, either FETs or bipolar transistors for each half of the input signal arranged in a push pull configuration, so that each device conducts for only one-half cycle of the output signal.

The amplifier is biased at its Q point therefore there is no need for a DC base bias current and with this remedy the DC power is small and hence raising the efficiency of the class B amplifier to a slightly higher level than that of class A. Increasing the efficiency of the amplifier has the disadvantage of introducing high level of distortion to the amplifier.

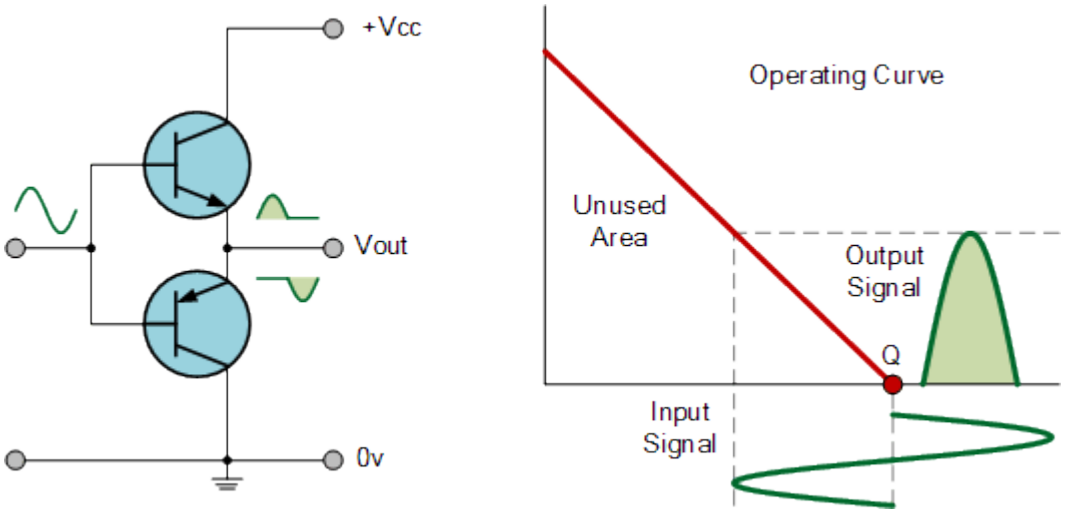

Figure 9: Class B push- pull amplifier and its characteristics (Genes P. , 1985)

During the positive half cycle of the input signal, the positive biased transistor conducts whereas the negatively biased transistor switches OFF. Similarly, during the negative half cycle of the input signal the negative biased transistor conducts while the positively biased transistor switches OFF. Thus, either of the active devices conducts for only a half a cycle of the given input signal.

From the above observation it can be seen that each transistor conducts for only one half of the input signal or 180° of each alternate half cycle, therefore at the output stage a device is introduced to combine the two halves to form a complete linear full wave signal.

The push pull arrangement of the amplifier raises the efficiency of the amplifier to about 50%, the only problem with such a design is that it introduces a distortion at the zero crossing point of the signal due to the active devices dead band of the input base bias voltage that ranges from -0.7v to +0.7v. This is because a transistor will not conduct until the 0.7v is exceeded; this means that the part of the signal that falls on the 0.7v platform will not be reproduced exactly as that of the input making class B amplifiers unsuitable for high precision stereo audio amplifiers. This type of distortion is known as cross over distortion.

Class AB- it is a combination of class A and class B type of amplifiers as the name suggests. This type of amplifier is the most popular type of all types of audio power amplifiers in design. It is a variation of class B amplifier designed to conduct simultaneously around the signals cross over point to eradicate the cross over distortion.

The two active devices have a small bias voltage of about 0.7 volts at the Q point current to bias the active device slightly above the cutoff point. This keeps the conducting device “ON” for over a half a cycle, but less than a full cycle of the input waveform. This means that the conduction angle of these amplifiers lies between 180° and 360° depending upon the Q point chosen to bias the transistor.

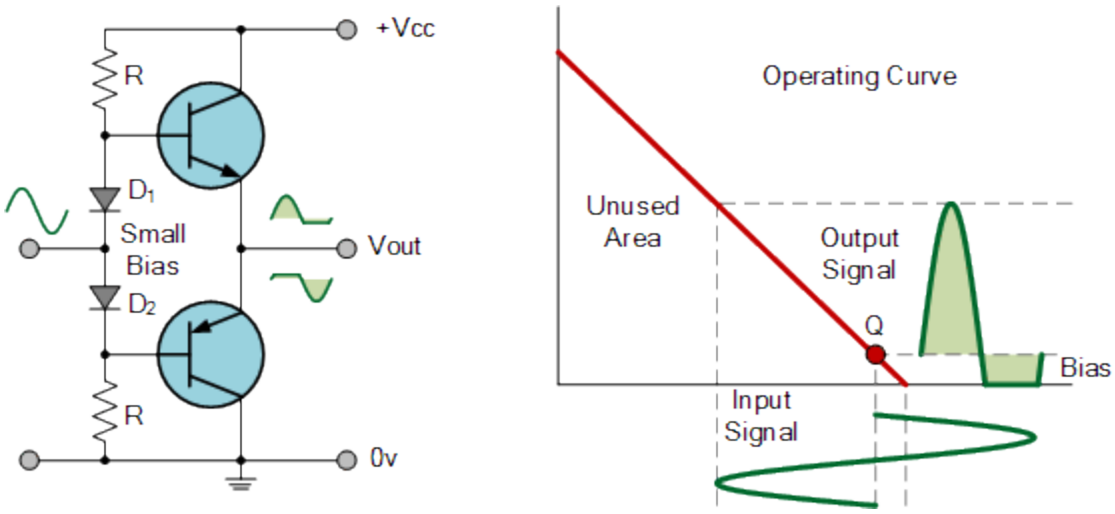

Figure 10: Class AB amplifier with its characteristics curve (Genes P. , 1985)

The merit of this small forward bias voltage given by series resistors or diodes is that the cross over distortion produced by the amplifiers is eliminated without a fall in efficiency as in class A amplifiers. Class AB amplifiers are a compromise between class A and B in terms of linearity and efficiencies reaching to about 50% to 60%.

Class c amplifiers- this design has the highest efficiency but suffers the disadvantage of having the poorest linearity of all classes of amplifiers described here. The other classes like class A, B and AB are said to be linear as the phase and the output signal amplitude are linearly related to the fed input signals phase and amplitude.

In class C amplifiers, the amplifier is heavily biased to make the output current zero for a period more than one half of the input cycle with the active device idling at the cutoff points. This means that the conduction angle of the active device is reduced to less than 180° and is approximated to around 90° region. This active device biasing gives an improved efficiency of about 80% to the amplifier but introduces heavy distortion of the signal output. Therefore, this class of amplifiers is ruled out for use in audio amplifiers.

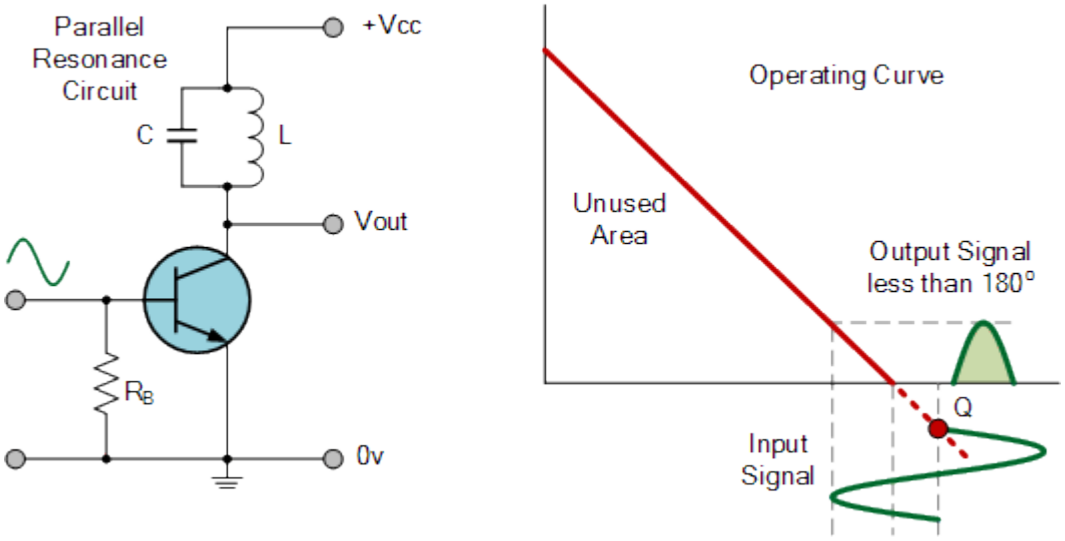

Figure 11: Class C amplifier with its characteristic curve (Boylesstand, 2013)

Because of the heavy distortion in class C amplifiers these amplifiers are commonly used in high frequency oscillators and radio frequency amplifiers, the pulses of current produced by these amplifiers can be converted into sine waves at certain frequencies by using resonant circuits.

In summary, the Q point of an amplifier determines the classification of the amplifier. Thus, the class of operation of an amplifier referred to its operating DC point can be illustrated as shown below:-

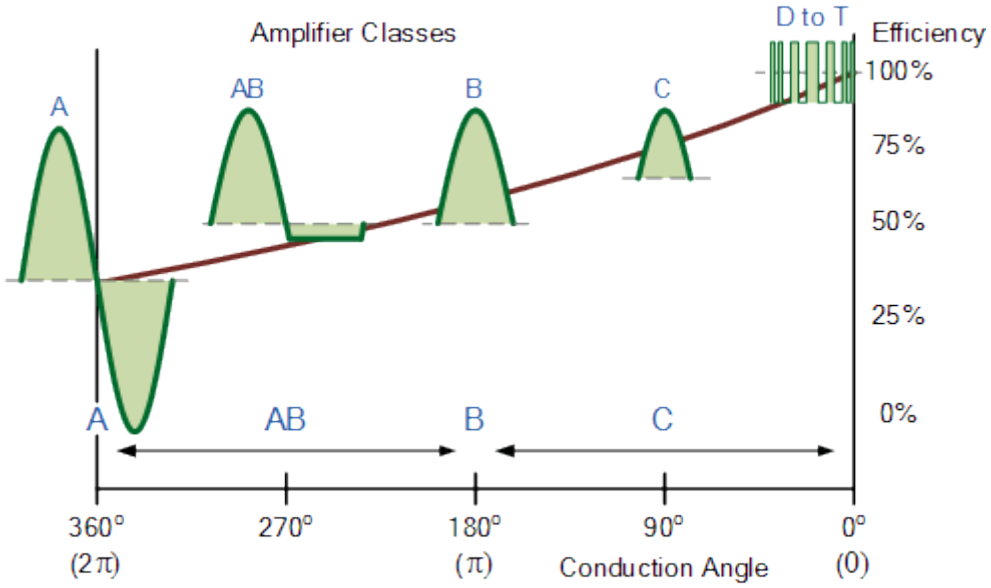

Figure 12: A graph of the characteristics of all classes of amplifiers (Finney, 1970)

The class C amplifier used for audio frequency signal amplification is called the klystron.

A klystron is a linear beam vacuum tube amplifier used for the amplification of high frequency radio signal, from ultra high frequencies (UHF) to microwave range. The klystron travelling wave tube is classified using levels of power i.e.:

i) Lower power klystron- used as an oscillator in terrestrial microwave relay communication links.
ii) High power klystron- used as output tubes in satellite communication, UHF television transmitter, radar transmitter and to produce the driving power for new generation particle accelerators

These tube amplifiers work on the principle that a cloud of electrons beam produced at the anode of the tube interacts with radio signals as it passes through cavities when travelling from the anode to the cathode. The beam of electron moves through the first cavity from where the input signal is applied. The energy associated with the beam of electrons amplifies the signal taken from the cavity at the end. This output signal is fed back to the input cavity to come up with an oscillator that generates radio waves.

Klystron amplifiers amplify radio frequency signals (RF) by changing the kinetic energy in the beam of electrons into RF radio frequency power. An electron beam generated by the thermionic cathode and made to travel over the tube through acceleration by high voltage electrodes typically with a rating of about tens of kilovolts. The beam is then guided through an input cavity called a cavity resonator. At this place radio frequency energy is put in the cavity with a frequency approximately equal to its resonant frequency that creates standing waves generates oscillations that acts on the beam of electrons.

The voltage causes the charge electrons to bunch, that is the charge electrons that travel through the tube when the voltage opposes their motion are slowed , whereas those travelling in the same direction as the electric field are accelerated, making the early group of electrons to form bunches at the frequency of the input. To rein force the bunching the klystron tube is made with extra activities.

The beam of electrons then passes via a drift tube where the faster electrons meet with the slower electrons that creates more bunches then travels via a catcher cavity. The catcher cavity is placed

at the output that allows only the beam of electrons motion that opposes the electric field that decelerates the electrons. Thus, the kinetic energy of the beam of electrons is changed to potential energy of the created field thus amplifying the amplitude of the oscillation coupled out. The oscillations that are excited in the catcher cavity are coupled out via a waveguide or a coaxial cable. A collector electrode collects the spent beam of electrons with reduced energy see figure below:-

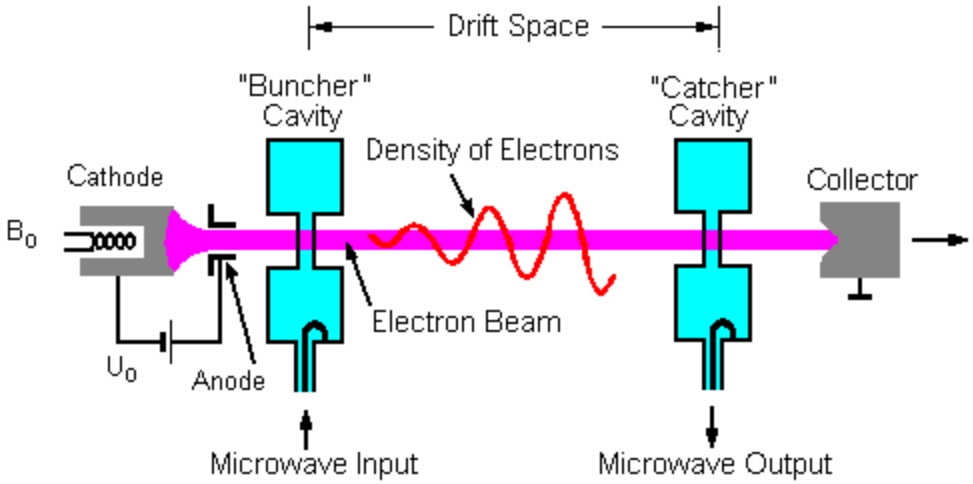

Figure 13: Klystron travelling tube amplifier (Sadiku M. , 1995)

2.6.3Filters

This .alternating circuits designed to separate one group of frequencies from others out of a mixture of different frequencies available in a circuit. The filters mostly applied in these circuits are electronics filters that can be divided into several categories. These categories are listed below as: -

i) Passive or active filters
ii) Analog or digital filters
iii) Low, high, band pass, band stop and all pass filters
iv) Linear and nonlinear filters
v) Finite impulse response or infinite impulse response

Passive filters – These filters are built by combining passive components such as resistors (R), inductors (L) and capacitors (C). These components do not require external power supplies and they do not have any active components such as diodes. Capacitors block low frequency signals and conduct high frequency signals while inductor block high frequency signals and conduct low frequency signals.

Active filters –These are made using a combination of active elements or amplifying elements with passive elements and because of the active elements involved they require external source of power for their operation. In designing active filters operational amplifiers are often used, they have the advantage of having high Q factor and attain resonance without the application of inductors. The only problem with these filters is that their upper cut off frequencies are limited by the bandwidth of the amplifying elements.

Digital filters- these filters are used in digital signal processing circuits because of the advantage of being cheap. In sampling an analog to digital signal, the signal is then passed through this filter and the end production is a series of pulses.

High pass filters – Filters designed to allow all frequencies above a cut off frequency $f_c$to pass through them and attenuates all the frequencies below these frequencies. The frequency response of such filters is as shown in the figure below:-

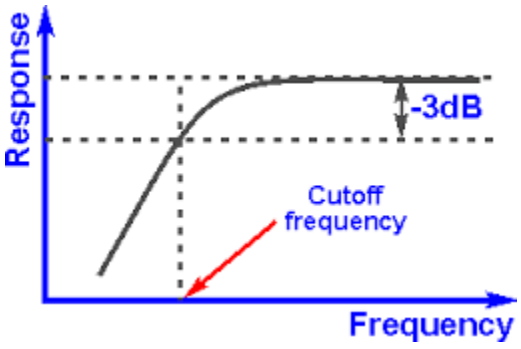

Figure 14: A frequency response curve for a high pass filter (Skurzynski, Electromagnetic fieds sensing, 1995)

The design of the active high pass filter using operational amplifiers together with passive components is as shown below

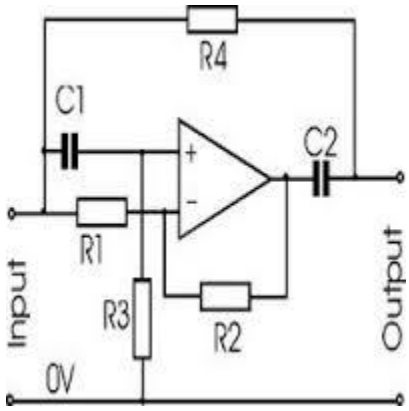

Figure 15: Operational amplifier high pass filter (Condon J. J., 2002)

Low pass filters- filters designed to cut off all the higher frequencies above a cut off frequency f_c and allow frequencies below these frequencies to go through it. The frequency response of the above filter is as shown below-

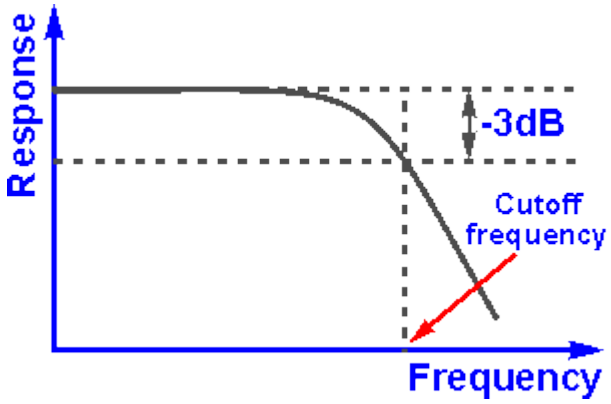

Figure 16: A frequency response curve for a low pass filter (Condon J. J., 2002)

The design of the active low pass filter using operational amplifiers together with passive components is as shown below

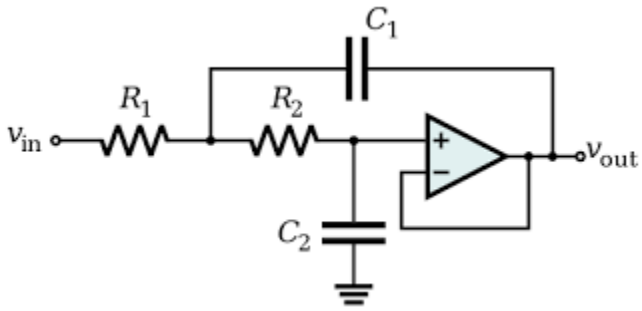

Figure 17: Operational amplifier high pass filter (Finney, 1970)

Band pass filters- filters designed to allow a group of frequencies between two cut off frequencies $f_{c1}$and f_{c2} to go through them and then attenuates all the frequencies below and above these frequencies. The frequency response for the above filter is as shown below:-

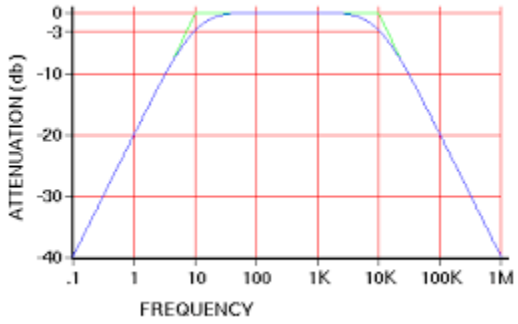

Figure 18: A frequency response curve for a band pass filter (Heinerman, 2003)

The design of the active band pass filter using operational amplifiers together with passive components is as shown below

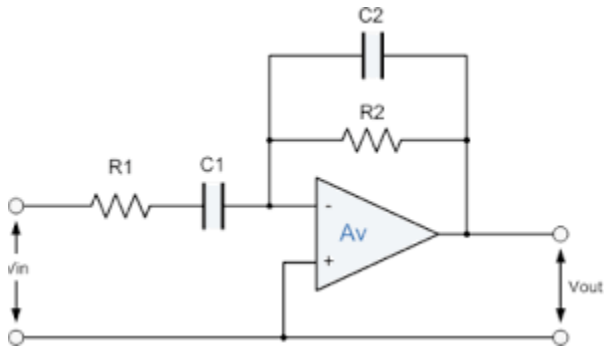

Figure 19: Operational amplifier Band pass filter (Boylesstand, 2013)

Band stop filter- filters designed to attenuate a group of frequencies between two cut off frequencies $f_{c1}$and f_{c2} and allow all those frequencies below and above these frequencies to pass through it. The frequency response for the above filter is as shown below:-

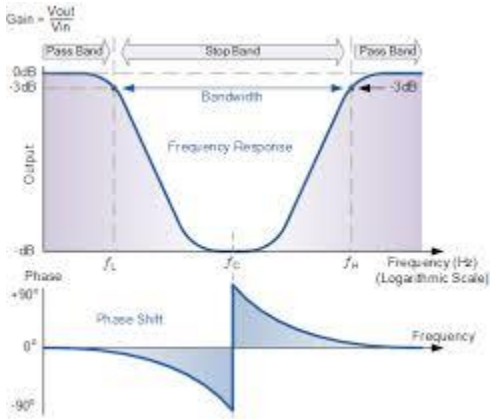

Figure 20: A frequency response curve for a band stop filter (Condon J. J., 2002)

The design of the active band pass filter using operational amplifiers together with passive components is as shown below

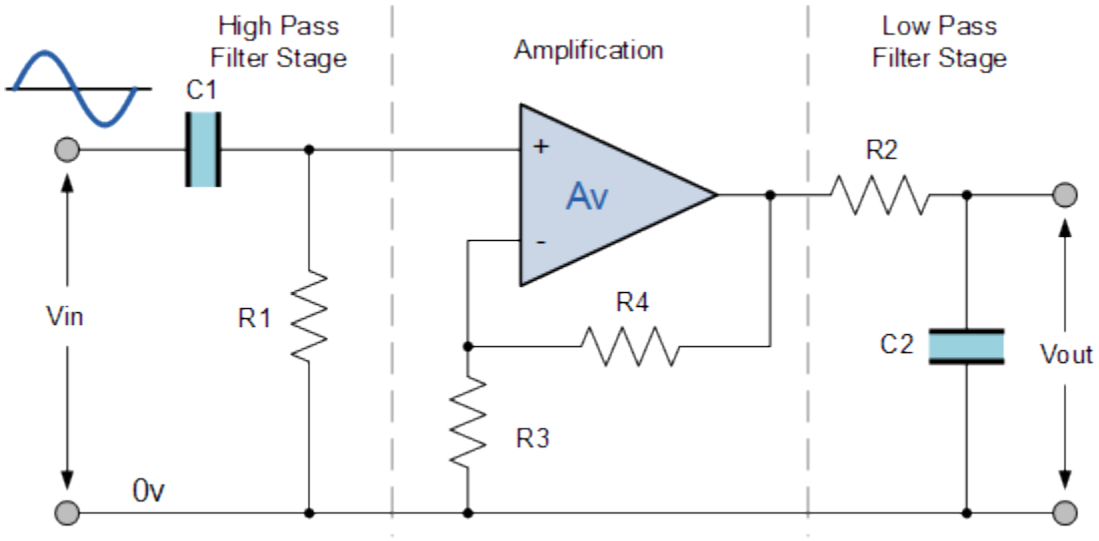

Figure 21: Operational amplifier Band pass filter (Finney, 1970)

Filters designed on component levels build structures give rise to the following design features:-

i) L-type filter- it consists of two reactive elements one in parallel and the other in series to produce two type of filters that is the low and high pass filters as shown below:-

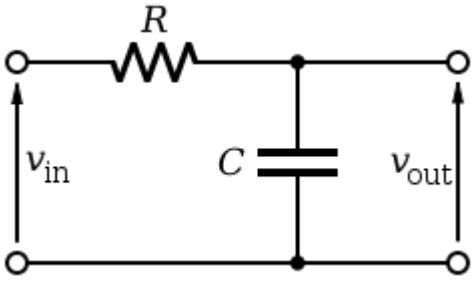

Figure 22: RC-L type Low pass filter

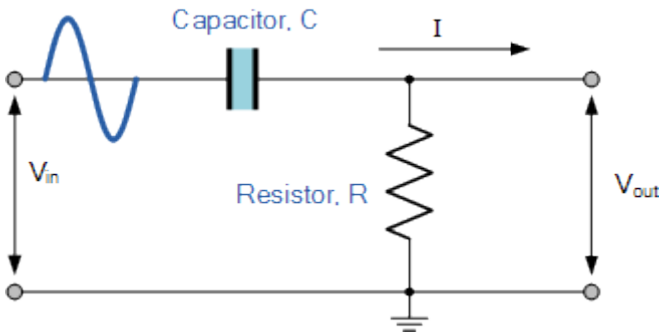

Figure 23: RC-L type High pass filter (Genes P. , 1985)

ii) filters- designed to have three reactive components one connected in series and the other two connected in parallel to give the two forms of pass filters that is the high and low pass filters as shown below:-

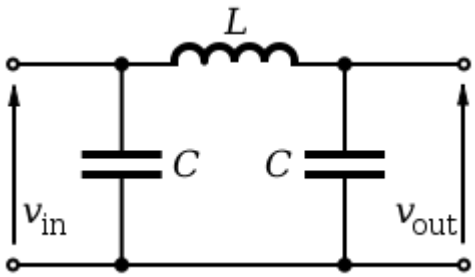

Figure 24: LC-π type Low pass filter (Condon J. J., 2002)

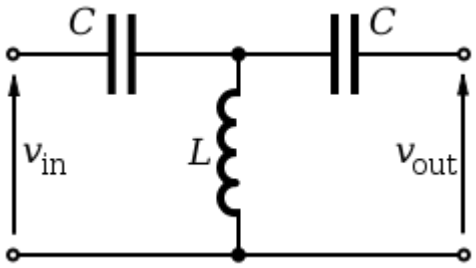

Figure 25: LC-π type high pass filter (Boylesstand, 2013)

iii) T- type filter- it uses three reactive elements but this time two placed in the series arm and the other one placed in the shunt arm, the T-type high pass filter has a high impedance at low frequencies and a very low impedance at high frequencies.

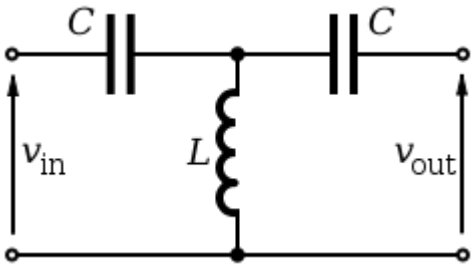

Figure 26: LC- T type high pass filter (Boylesstand, 2013)

The T-type low pass filter has a low impedance for low frequencies and a high impedance for high frequencies see the figure below.

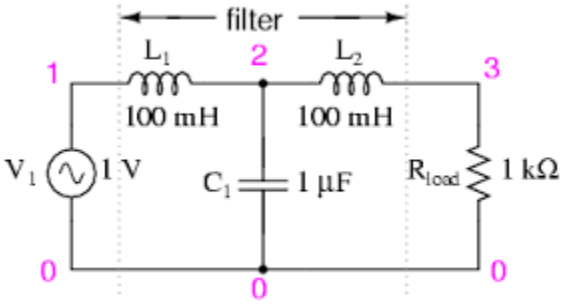

Figure 27: LC- T type Low pass filter (Fisherman, 1994)

2.6.4The Low Noise RF Amplifier

This is responsible for the amplification of the low noise signals, which are very weak signals from the detected spectrum, these signals are in the form of radio frequency signals that provide the detected information and need energy to support

2.6.5Mixer

The signal form the RF amplifier fed to a mixer stage that combines the radio frequency signal with another signal generated from the inside of the receiver by an oscillator called the local oscillator. The purpose of the mixer is that it uses its nonlinear device characteristics to produce a beat of frequencies.

The output from the mixer includes the local oscillator frequency signal, the original radio wave signal, and additional two other components that is the sum of two and difference of the two signal i.e. the radio frequency signal and the local oscillator frequency that can be seen to work as follows $f_{c1} + f_{c2}$ and $f_{c1} - f_{c2}$.

In addition to these components, the mixer has the ability to produce more signals at higher frequencies that are the harmonics of the two lower frequencies and higher order inter-modulation products. These many products of frequencies are referred to as heterodynes.

2.6.6Local Oscillator

These circuits meant to generate frequency signals from the inside of the receiver itself. It usually produces higher frequency signals of the form of sine waves. These signals generated help the receiver to select different channels in the system as required by the user of the receiver.

2.6.7 Spectrum Analyzer

The signal processing in digital receivers works as follows. The processor that is attached to the detector will receive the intermediate signal IF signal through a spectrum analyzer. The IF signals is an analog signal that has to be converted to a digital signal by an analog to digital converter. The analog to digital converter is a system that changes analog signals to digital signals. It can provide specific measurements for the conversion of either analog voltage or current to digital voltage or current. The output will be in terms of digital twos compliments that is directly proportional to the applied input.

The conversion process of analog to digital signals involves several processes as shown in the block diagram, which include:

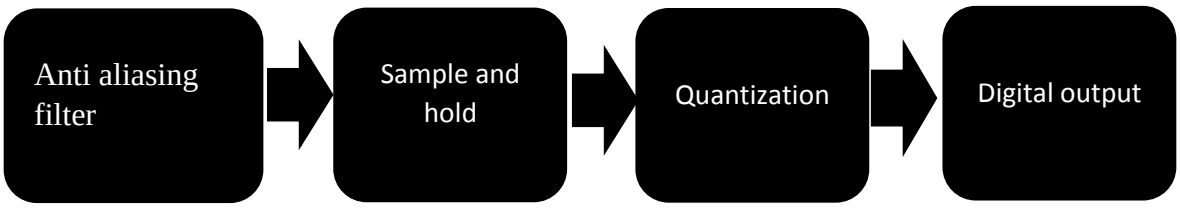

Figure 28: A block diagram of digitalizing process

a) Sampling

Since the signal is a continuous signal with time it becomes necessary to convert the signal to discrete form, it is required to determine the pace at which the new signal digital values will be sampled that is broken down from the analog signal. The rate at which these values are broken down is called the sampling frequency or sampling rate of the converter.

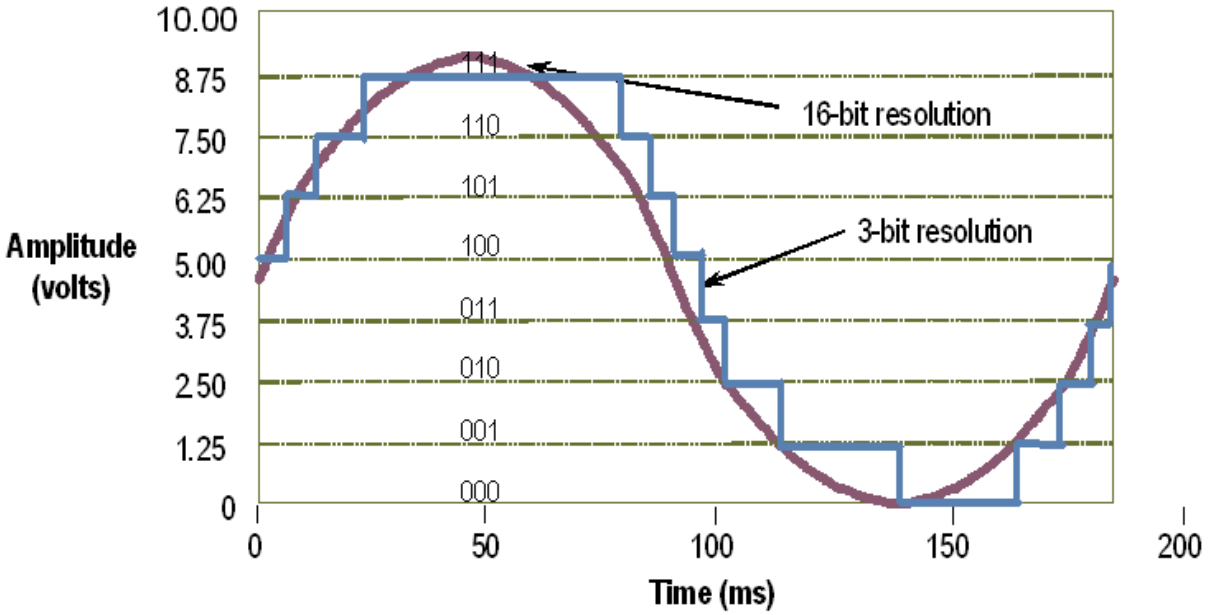

Figure 29: Sampling diagram (Condon J. J., 2002)

The band limited analog signal will be sampled and the reconstructed into the original but discrete signal by the use of interpolation formula. Sampling is normal followed by quantization that produces quantization errors. The rate at which sampling takes place is given by the Shannon-Nyquist theorem that states that the sampling will only take place if the rate of sampling is higher than double of the highest signal frequency.

Practical ADC hold the input for a specific time before releasing it to the next stage during the sampling rate, this period when the input is held for conversion is called the conversion time. This process is made possible by a circuit that is called sampling and holding circuit that is made of a capacitor that stores continuous voltage at the inlet and then by the use of an electronic switch such as a semiconductor mosfet gate, the capacitor can be controlled like being switched ON and OFF from the input.

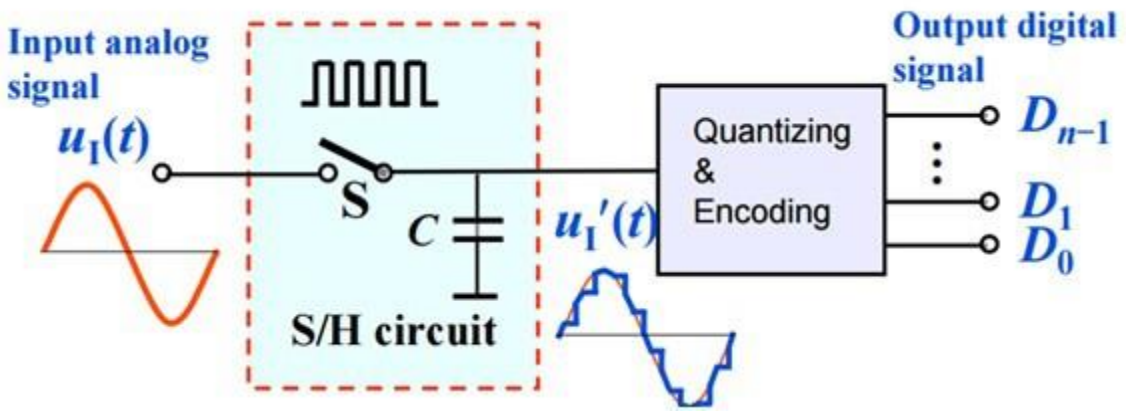

Figure 30: Sampling diagram and hold circuit (Genes P. , 1985)

b) Quantization

This is the process of assigning values to the sampled signal; it can be referred to the rounding off the output-digitized values and to assign them specific values. In this rounding off an error occurs between the actual value of the output-digitized value and the input analog value that is called the quantization error. This error when evenly distributed can be calculated as follows:

SQNR = $20log_{1o}2$

= 6.02QdB…… (1)

Where Q is the number of bits in the quantized sample

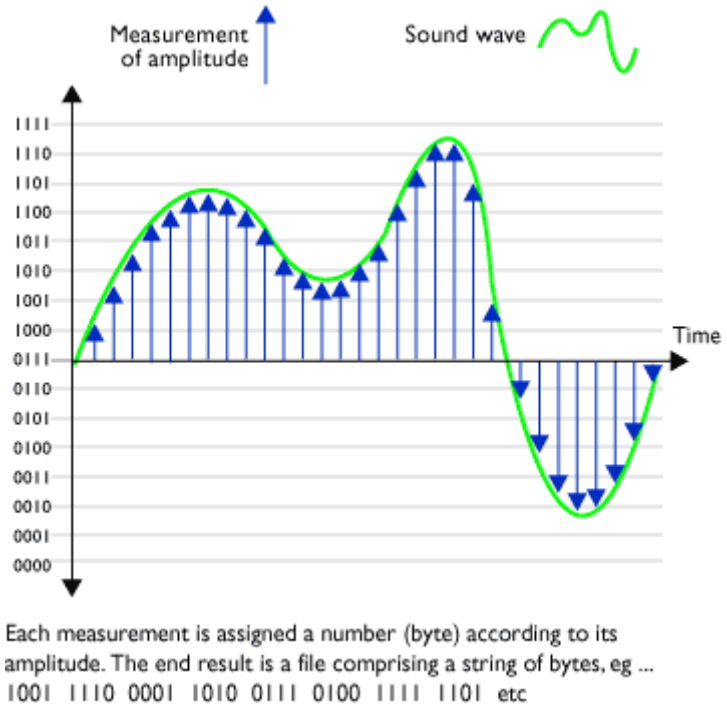

Figure 31: Quantization diagram (Skurzynski, Electromagnetic fieds sensing, 1995)

c) Resolution

This gives the number of digital values that the converter can produce or the given range of the values that are in analog. It determines the size of the error and at the same time the SNR of the converter without over sampling. Since the values are stored in digital, form the resolution of the converter is expressed in bits. As a result, the number of digital levels or values available is given in the powers of two.

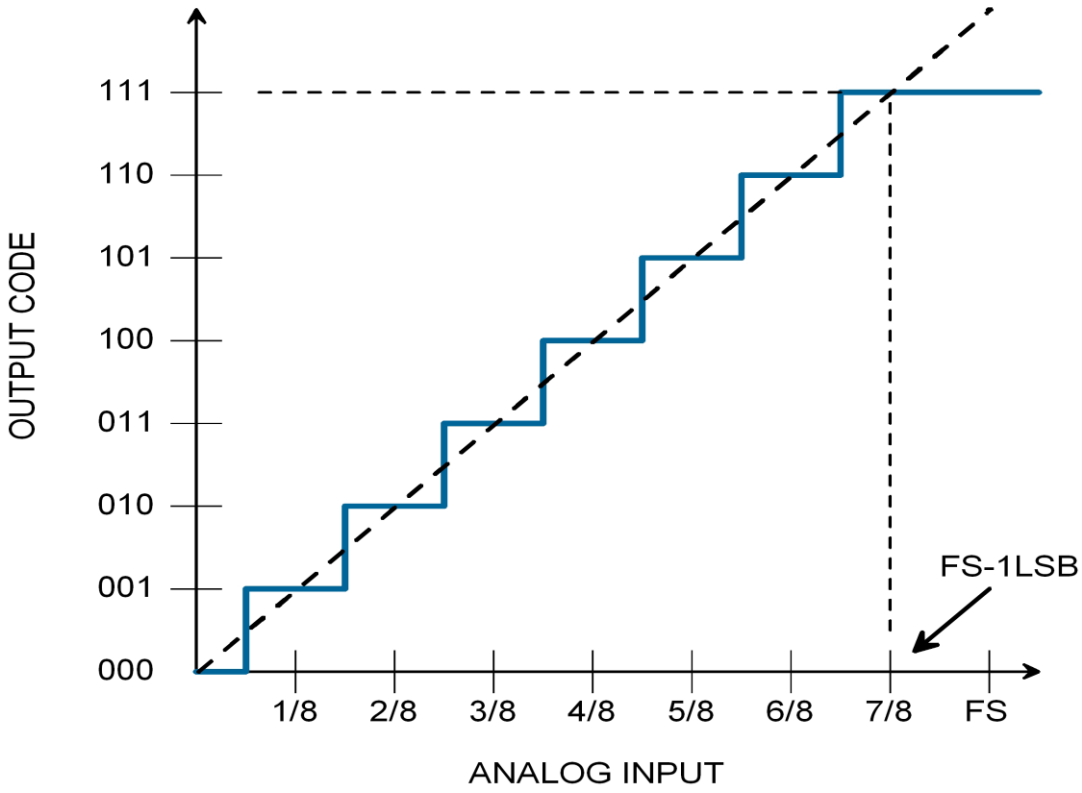

Figure 32: Sampling error diagram (Condon J. J., 2002)

Resolution is also electrically defined and may be expressed in volts. The LSB last significant bit is the minimum change in the converted voltage that is required to produce a change of code at the output level. This LSB voltage of a converter is equal to the resolution and can be calculated as follows:-

$$Q = \frac{EM}{2^N - 1} \quad \ldots\ldots (2)$$

Where Q = Resolution

E = Full scale voltage range

M = ADC"s Resolution in bits

d) Aliasing

This is when frequencies higher above the half Nyquist rate are sampled and are seen as low frequencies. It occurs because sampling instantaneously a function fewer rate per cycle produces

absent cycles that results to the emergence of incorrectly lower frequencies. To correct this situation a circuit at the input of the converter usually a low pass filter is connected to filter out the frequencies over half the level of sampling frequencies. Using aliasing filters is optional in order to avoid the use of aliasing filter the process of over sampling cab be utilized.

The analyzed signal is then filtered and converted into a low base band signal. The processor in the spectrum can generate up to ninety thousand signal samples that are complex per second. The processor will also do a filtering of the signals on the data sampled on the lower and uppers side bands based on the Centre carrier frequency of the TV receiver on the allocated group of channels.

All the analyzed powers of the detected signals are measured with reference to the aerial. Before calculating the power received, the gain of the successive stages is measured across the entire frequency range. Calibration of the signal path is necessary so that we have an accurate value of the phenomenon being measured.

Every sensing element is time synchronized with the device of a general position sensor (GPS) system receiver. In aligning the sensor this way several sensor can receive the TV signals within $10d_B$ within the same time. The output can be connected to a computer and the data analyzed.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This refers to how the research study is carried out and the ways or procedures the data are analyzed. Methodology shows the different steps that are adopted generally by the person carrying the research study and the reason behind the research.. Adaptation of the method used is in the dispension of the researcher's decision to make the appropriate choice to solve the problem involved in his research. Therefore, it is the responsibility of the researcher to design a method that is capable of solving the problem at hand. The methodologies differ from one area of a problem to the other.

The decision the researcher makes in approaching the research study will deliberate on the design of the research. The person carrying the research must always come up with the right choice of the design to enable him to solve his problem.

3.2 Research Methods Used

In studying the spectrum to be used by the tool for detecting and distributing of TV white space two methods are usually used, these are the prototype and the experimental methods.

3.2.1 Prototype

The primary idea for employing a prototype is that in this device instead of reducing the needs before a coding or design to go on, a throwaway prototype device is constructed to give an understanding to the required needs. This prototype device is developed on the basis of the currently known requirements. By the use of this prototype device, the buyer can get to understand the needs of the required system.

The idea of prototyping is attractive for large and complicated systems for which no existing or manual process helps to determine the requirements,

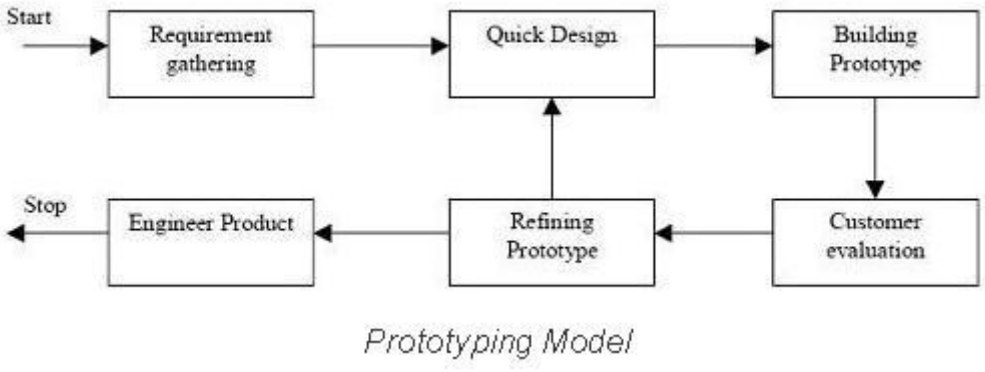

Figure 33: Prototyping model

3.2.1.1 Advantages of Prototype Model:

i) In the development of a prototype the user is actively involved
ii) The user gets a good understanding of the device being developed, since in this prototype methodology a model that is working is provided.
iii) Errors in the system can be discovered much earlier
iv) Better solutions can be available due to faster user of feedback.
v) Easy identification of missing functionality
vi) Difficult or confusing functions may be identified. quick implementation, requirements validation of incomplete and functional application

The prototype is used when:-

i) These models should be utilized when the required device needs to have many interactions with the users
ii) Typically, web interfaces online possess a good portion of interaction with the users at the end and are qualified to be used for prototype models. It takes a while to build the system that permits ease utilization and requires minimal technical knowhow for users.
iii) It ensures that the end consumers work constantly with the system devices and provides feedback that can be incorporated to the prototype model to give a usable system. Prototypes are excellent when designing systems with good computer human interface

3.2.2 Experimental Research

This is the collection or gathering of research designs that uses controlled testing and manipulation to understand the knowledge of the casual process. In generally the manipulation is done on one or more variable to determine or find the effects of this controlled variables on the dependant variables.

3.2.2.1Advantage of Experimental Research

i) Control over variables- experimental research helps controlling variables that are independent for experiments specific objectives' to remove unwanted and extraneous variables. The monitoring and controlling of variables that are irrelevant is of higher rate in comparison to other types of research methods.

ii) It becomes easy to determine the effect and cause relationship. The experimental design in this research types includes independent variables manipulation to determine easily the effect and cause relationship.

iii) Better results – due to strict conditions and set up controls better outcomes can be achieved.

iv) The experiments can be re done and the results rechecked

v) The better results achieved also can give the person doing the research higher confidence regarding the achieved results.

vi) Experimental research enables the researcher in obtaining insights to set instruction methods, doing experiments, mixing and combining different methods for rigidity, best determination of population and providing higher transferability..

vii) Research may involve personal biases, artificial results, unreliable samples, and results outcomes that are limited to one particular situation and might become difficult to replicate.

viii) Time consuming and expensive

ix) Designs that are experimental in nature are frequently scenarios that are contrived they do not imitate the exactly situation of the real world.

But for this project the experimental method was chosen.

3.3 Research Tools

3.3.1 NS-2 Network Simulator Version 2

It was first deployed into the market in 1989 and it was using real time network simulator. It is supported by DARPANSF. It is an event discrete simulator for network and it was made for object oriented tools that command C++ programming language.

The tool can run best in Linux operating system; it is an open source type of simulator that provides document on line.

Advantages:

i) NS-2 is a non-specific simulator that can support a wide range of protocols for all network layers.
ii) It is cheap
iii) Its characteristics of having docu8ment online permits the end users to improve and modify the codes

3.3.2 Tossim

An emulator made specifically for wireless sensing networks WSNs runs on tiny operating system. An open source targets embedded operating systems. It was developed for the first time in 2003 by Berkeley's project team. It is a bit level event discrete network system emulator and built in python, it uses a high- level program language that emphasizes on code readability and also uses C++. It provides documentation and can be employed on Linux, or Cogwin operating systems running on windows.

Advantages

i) It is cheap since it's an open source system
ii) It can model online document free and therefore saves cost
iii) It is scalable and support greater nodes.
iv) Provides precise results of simulation at component level since it can compile directly to the native codes.

3.3.3 EMstar

This simulator is specifically made for wireless network that are built in C. its trace driven simulator that runs on real-time. It is used on Linux operating system. It is mostly used on hardware sensors.

Advantages

i) The programming is done in modular form and this permits the applicants to run the modules separately without the need to sacrifice the usability of the software.
ii) The robustness of this software enables it to explore faults among sensors.
iii) It offers standard interface that can easily connect to other services.
iv) It has GUI that is advantageous to end users for controlling electronic devices.

3.3.4 OMNeT++

A network simulator that is built in C++ language. It provides both commercial and non-commercial license. In non commercial application it is used for non-profit organization doing research or at academic institutions. OMNeT++ supports programming in modules. It can be run on windows, Unix-like system and Linux operating systems. It is non specific popular simulator and can be applied for both wired and non-wired areas that is wireless. The simulation models are open sources.

Advantages

i) It provides GUI that is a powerful tool that makes debugging and tracing easier than in any other simulating system used.
ii) It supports both MACs and localized protocols for WSNs
iii) It can simulate channel controls and power consumption problems found in wireless networks.

3.3.5 OPNET

This tool is used in the project Opnet (Optimised Network Engineering tool) is specially designed for development and research of networks. It is flexible and can be used to study devices,

communication networks, applications and protocols. It offers much powerful graphical or visual support for end users.

To construct network entities and topologies from the physical to the application layers, graphical editor interface that is in the software can be utilized. Object oriented programming languages and techniques in this modeler can create mappings from these graphical design and implement them into real systems.

It utilizes a mechanism that is referred to as a discrete event system that means the behavior of the system can simulate through modeling the system events in the set of orders of the scenes that end user has already set up.

Opnet has the characteristics of providing programming tools used for defining packet formats for the protocols. The introduction of GUI interface together with programming tools helps the users to construct any type of a system in demand. The main characteristic features that make opnet best for research of wireless studies is that it has:-

i) Simulating
ii) Modeling
iii) Analysis

In modeling, it produces intuitive graphical environments for creating all kinds of modeling protocols. In simulating, it utilizes three advanced simulation technologies to address a wide scope of studies. It displays and analyzes easily, analysis, results and data from simulation. This modeler produces user-friendly charts, statistics and animation for the convenience of the users.

This modeler will verify the following tests:-

i) Checking within a candidate channel if any protected service is present and transmitting.
ii) When a channel is found to be vacant sensing is typically applied to adjacent channels to identify if any constraints on power are present.

The presence of the protected service is obtained by measuring the threshold value of power of the transmitting device, the device is allowed to transmit otherwise keep silent or looks into other channels. The assumption made here is that the frequency of interfering wireless device depends on the frequency range defined for the victim.

3.5 Setting of the Experiment

In the setting of the experiment, a software tool that is called the river bed modeler academic edition version 4.7 is utilized. The modeler has such features as File, Edit, License, Windows and help. See the figure below

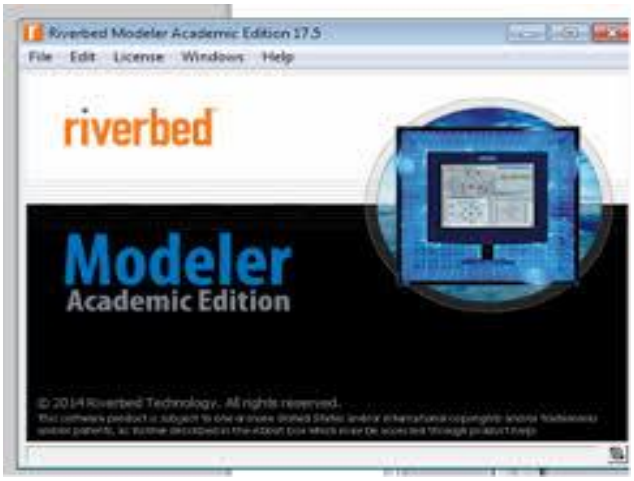

Figure 34: A sample of the riverbed modeler

Click the feature File and the operating task under file will be featured, click the item New, and a task bar will confirm that anew project under test is to be created. Indicate the task to be tested that is the project title and click okay.

A start tool bar will appear to help the under designed to create the required scenario to be tested. It comes out with features such as topologies options that one is supposed to utilize in setting up experiments as required by the experimentally parameters such as area, distance and the type of technology to be used.

Once the scene has been created an object palette is displayed such as the one given below to help the user to create the required scenario.

Node	Access point	Server	Sensing	Switch	Application	Profile
Icon						

Figure 35: Application node tools

Use the mouse cursor to drag the required nodes from the object pallet to the scene under test, for this project the following items are required:-

i) A distance server that will act as the source of the white space from where the information about this space is required.
ii) A switch that serves as a distribution point to a multiple of receivers
iii) An access point which act as a receiver antennae and the will also act as the distribution point to the local users
iv) The wireless workstation that will also act as the local receivers, receiving the information from the distance transmitter receiver to be analyzed.

In addition to the nodes a link is required to connect the access point, the switch and the distance transmitter, the most suitable link is 100 base T duplex links and above that has a good data carrying capacity. Two utility nodes are available in the palette to help link the nodes these are:-

i) The application configuration whereby it will be used to configure the device according to the services they are going to provide.
ii) The profile configuration where it is going to configure the receiving device according to the required services provided.

These two nodes are important in that they help the devices under test to communicate. The scenario will appear as given below:-

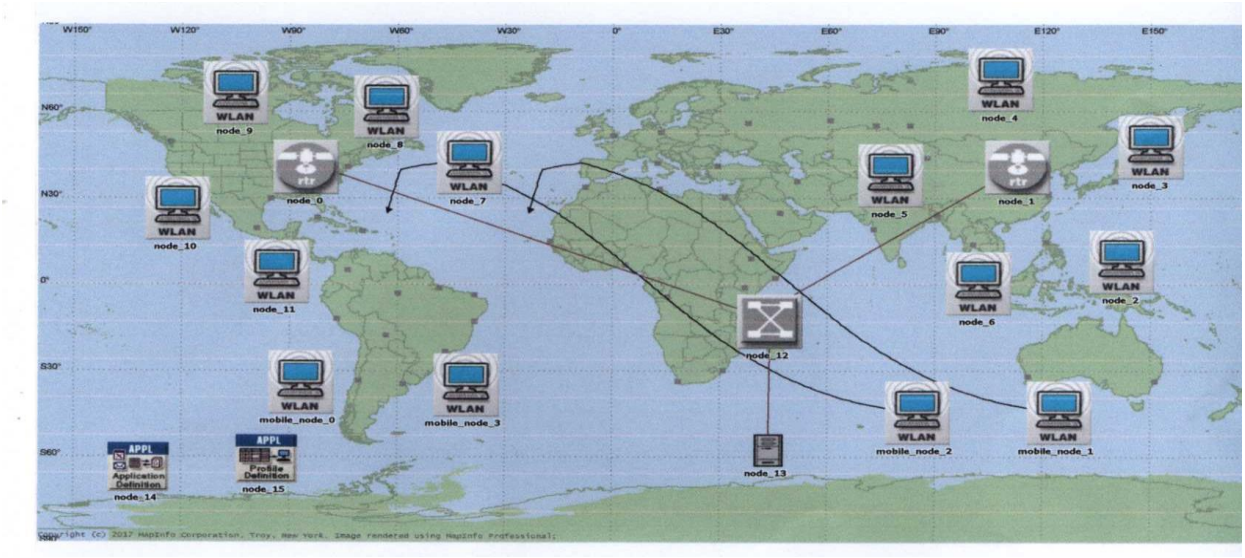

Figure 36: Modeling scenario

Configure the devices in the test scenario; the configuring of these devices is referred to as modeling attributes. Start as follows:-

Access Point

Node Model: wlan_ethernet_slip4_adv

Wireless LAN Parameters:

BSS Identifier: same level number as the associated Workstations Access Point

Functionality: Enabled Operation

Mode: 802.11g,

Data Rate: 54Mbps

Transmission Power: 0.005W

Dimensions of WLAN network: 100m x 100m,

Workstation

Node Model: wlan_station_adv

BSS Identifier: same level number as the associated AP

Supported Application: varies correspond to different scenarios

Access Point Functionality:

Disabled Operation Mode: 802.11g,

Data Rate: 54Mbps

Transmission Power: 0.005W

Switch

Node Model: Bay Networks Accelar1050

Server: supported services

Node Model: ethernet_server

Application Supported Services: All

After configuring, the devices now configure the nodes that will help in communication between devices. These are-

Application

Node Model: Application Config

Application Definitions: Default (It includes 8 applications with high load and low load for each. Email, File Transfer, Web Browsing, File Print with high load are used for this project)

Profile

Node Model: Profile Config

Profile Configuration: choose the applications using for correspond to different scenarios

Data Rate: 54Mbps Transmission Power: 0.005W

SwitchNode Model: Bay Networks Accelar1050

Server: supported services Node Model: ethernet_server Application Supported Services: All

ApplicationNode Model: Application Config Application Definitions: Default (It includes 8 applications with high load and low load for each. Email, File Transfer, Web Browsing, File Print with high load are used for this project)

Profile Node Model: Profile Config Profile Configuration: choose the applications using for correspond to different scenarios

A physical configuration on the network is required; this is done by clicking the protocol task in the tool bar this will give you the physical and data rate configuration tool bar of which it will give the different standards as used by different wireless technologies. T.V white space uses wireless technology that is more advance than the ordinary WI-FI system that has more power and for this reason it is called super WI-FI but it uses the same standard as the ordinary WI-FI that

is 802.11 standard of communication for wireless local area network WLAN. IEEE 802.11a, IEEE802.11b, IEEE802.11n and 802.11g are the protocols that are commonly applied in our present day environment. For this research project the 802'11g protocol is going to be utilized.

Table 1: Wireless Standards (Boylesstand, 2013)

	Standards		
Parameters	802.11a	802.11b	802.11g
Frequency	5GHz	2.4 GHz	2.4 GHz
Channel	19 channels	1124 MHz channels	
Bandwidth	54Mbits/s	11Mbits/s	52 Mbits/s
Realistic maximum throughput	25Mbits/s	6Mbits/s	25Mbits/s
Compatibility	Not compatible	Not compatible	Compatible with b
Range	Up to t 50m	Up to 100m	

Since its wireless Ethernet the standard picked is 802.11g and the data rate capacity is 54Mbps.

From the tool bar click, the DES task that allows the user test the different parameters under test in this test the parameters required are-

The detected hole will be tested on:-

i) Delay
ii) Power received
iii) Power of moving a sensing device
iv) Comparison on power received by single and multi transmitters

CHAPTER FOUR: DATA PRESENTATION, ANALYSISAND DISCUSSION OF RESULT

4.1Introduction

This chapter contains a visual or written presentation that outlines and explains either narrative or graphically forms of the main items of study, especially from the main objectives. The findings of the research based on the objectives and the analysis of the results.

4.2 Results

The result of the findings can be summarized according to the given model that is driven from the main objectives as shown below:-

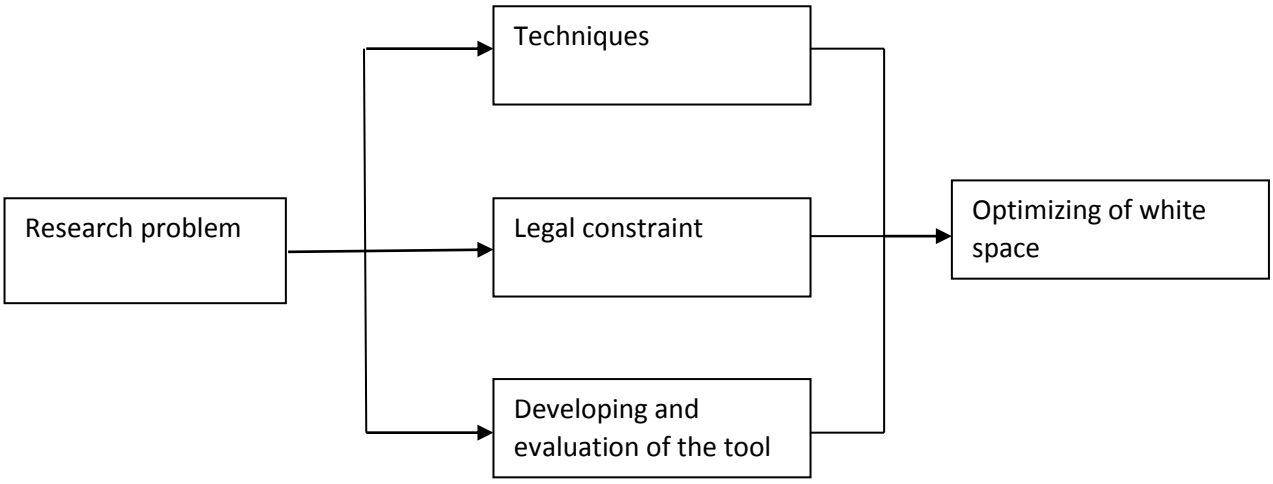

Figure 37: A model of the results analysis

4.2.1 Techniques

The two techniques identified for spectrum sensing in this project are-

i) Coherent detection and

ii) Energy detection

They two can be sensed from either the transmitter or receiver end of the sensing device. See the figure below

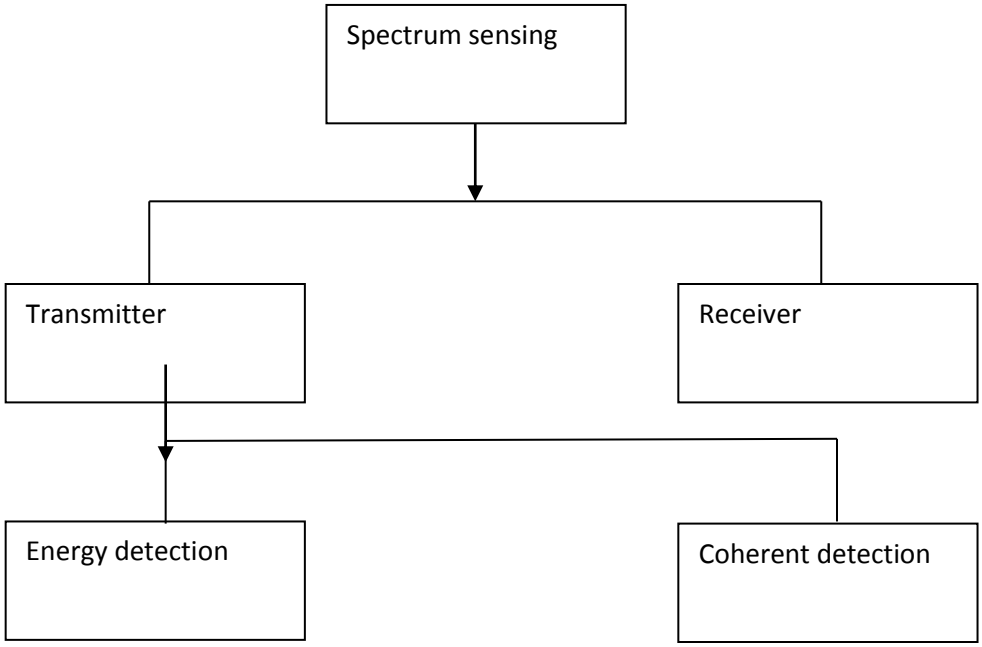

Figure 38: A model of the sensing techniques

Two tests were carried out on these techniques one was to find there sensing capabilities on noise environments and the following results were obtained.

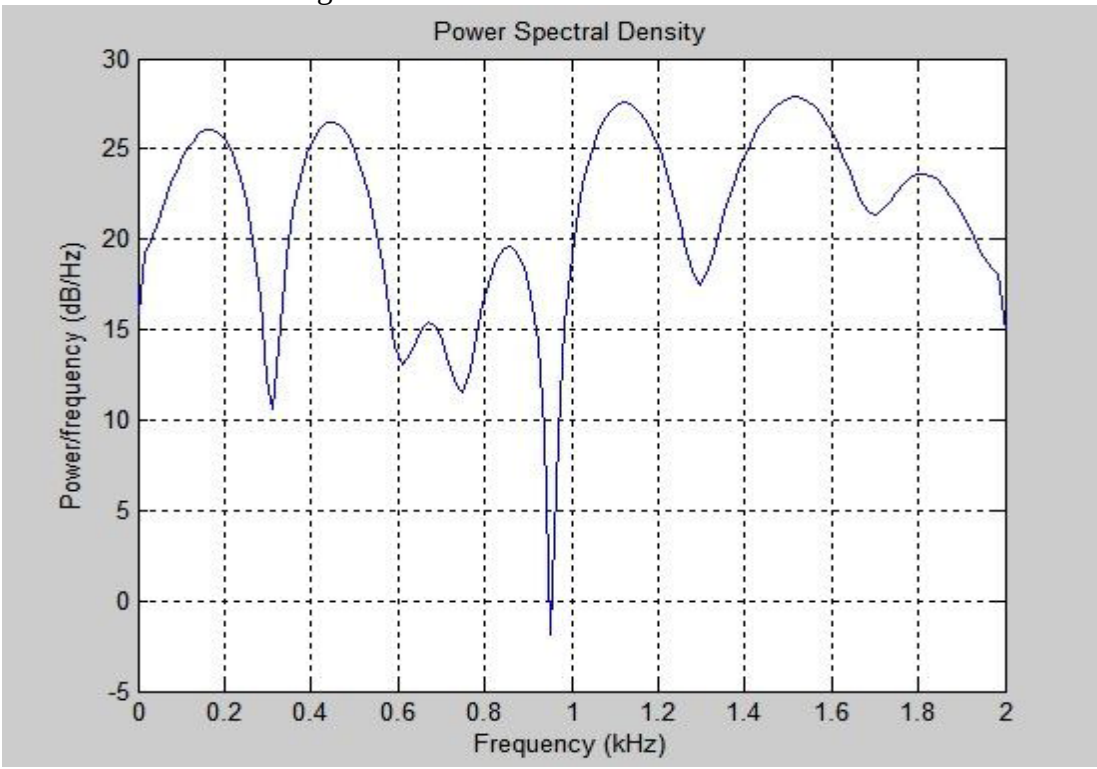

Figure 39: A graph of power against frequency for coherent detection

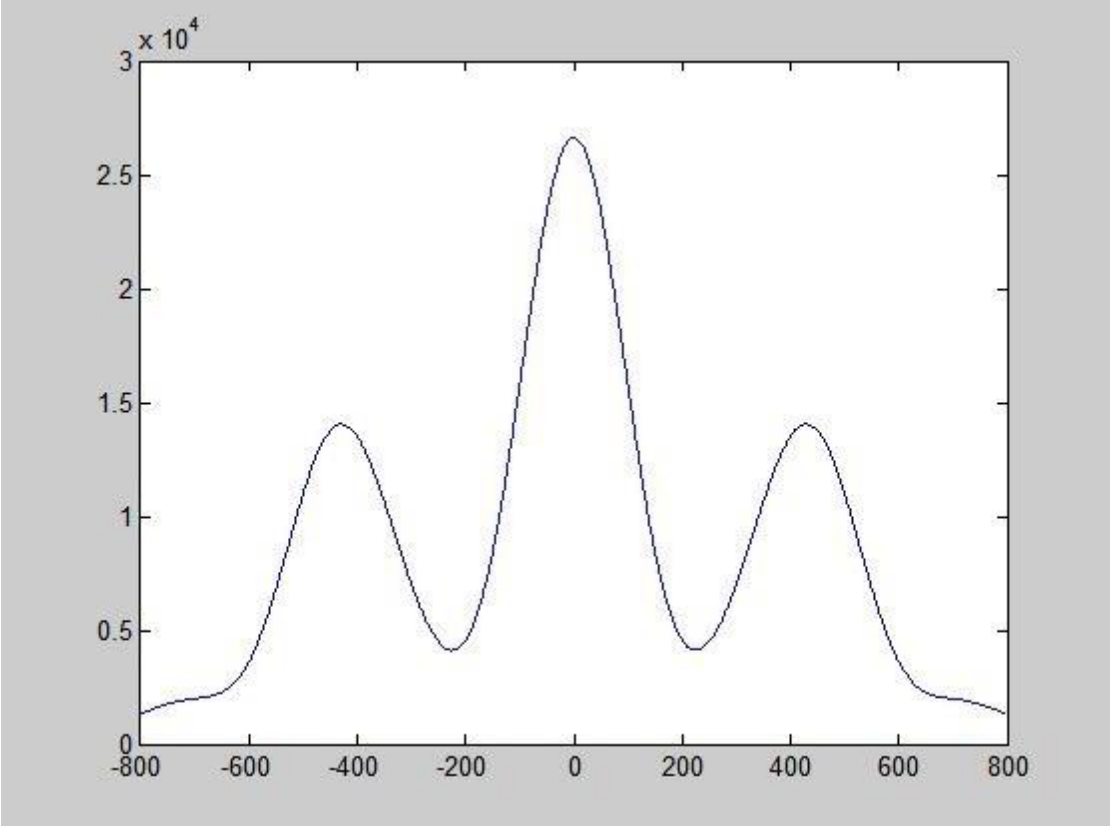

Figure 40: A graph of power against frequency for energy detection

Itcan be seen from the two graphs that coherent detection has a good spectral frequency spectrum that show that in a noise environment the preferred method of detection is coherent method.

When the two methods of detection are tested against time of sensing the signals the following table was obtained

Table 2: Time response of sensing methods

Serial No.	Type of primary signal	Energy method	Coherent method
1	BPSK	1.20 S	9.3S
2	QPSK	1.23S	11.21S

The results indicates that energy method has a faster response towards received signals than that of the coherent methods this is due to the fact that the coherent method has to eliminate noise when sensing the signal.

The choice of the sensing methods can be summarized in the graph show below

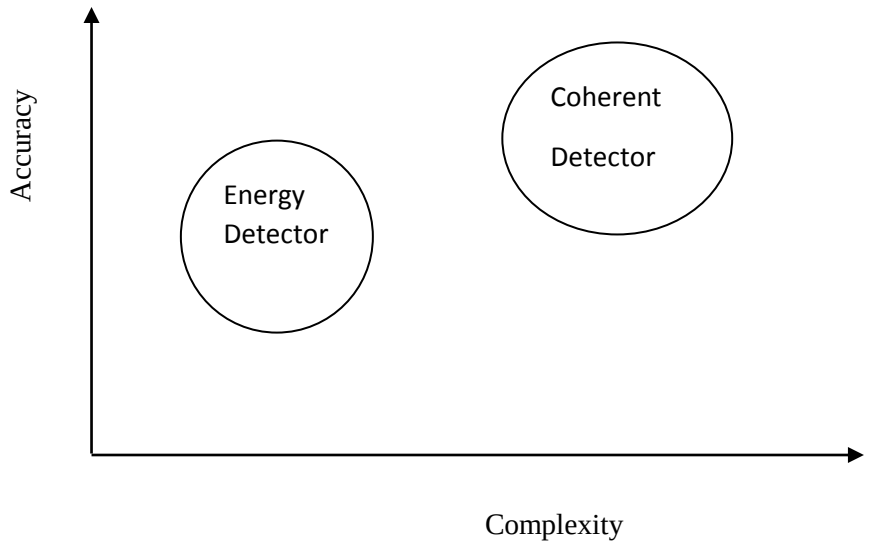

Figure 41: A graph showing the comparison of the two methods

This indicates from the graph that in order to use any of the methods there are factor to be considered and these factors are cost, simplicity and accuracy. For simple and cheap experiments energy detection is utilized and for more accurate result oriented experiments coherent method is utilized although complexity goes with cost.

4.2.2 Legal Constraints

The legal constraints identified can also be identified into two

i) Sensing period
ii) Detection sensitivity

These constraints are controlled under a legal framework from the (ITU) International Telecommunication Union, which offers legal licenses and permits to the usage of the spectrum, the model of ITU control is illustrated as shown below

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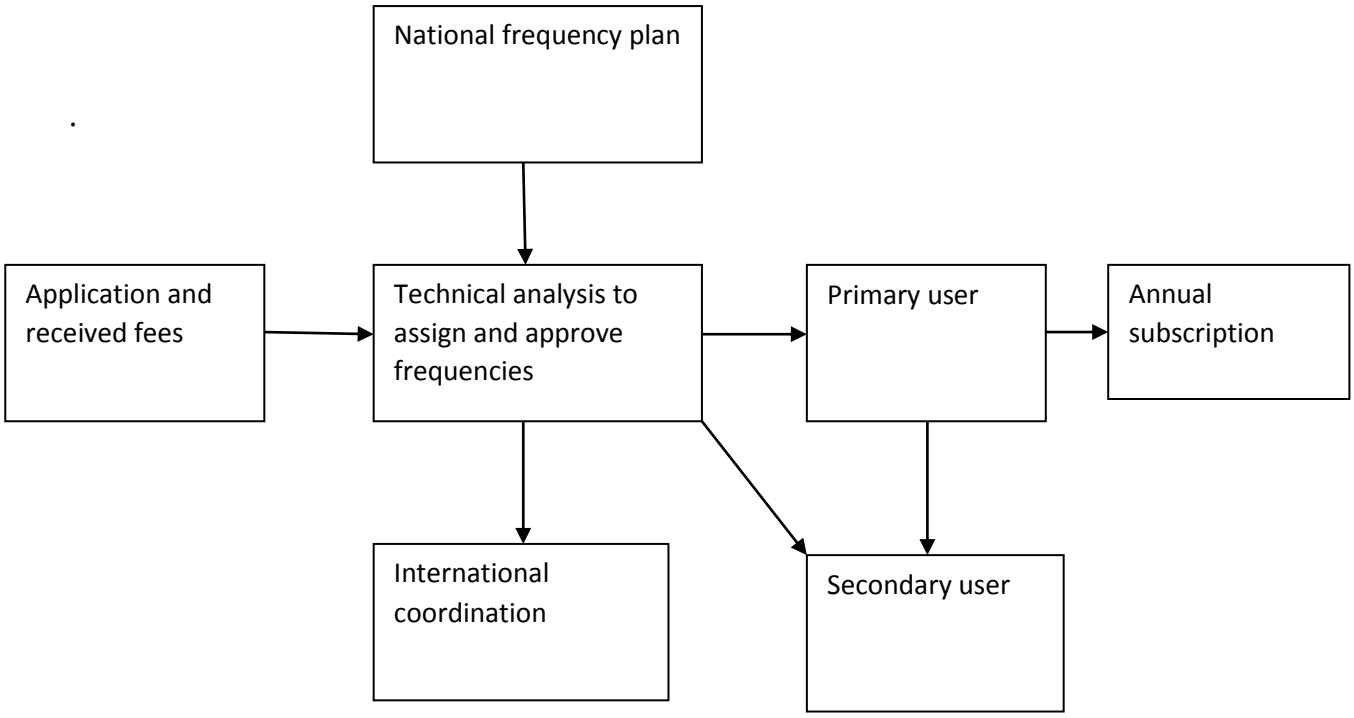

Figure 42: Legal constraints model

In this model, the findings are that any new entrant or player to this field has to apply for a license from the technical section. The technical section then checks if there is vacant area in the spectrum that can accommodate the requested frequencies. After the analysis the technical section in collaboration with national frequency allocators and the international coordination are able to approve the required frequencies.

The secondary user has two alternatives to choose in order to sense the spectrum, these alternatives are

i) Hire the spectrum from a primary user when the spectrum is not in use or
ii) Obtain a permit or license from the technical section

If the frequencies are obtained from the technical section two legal demand are to be met and these are

i) Sensing period where the user is given a fixed sensing period to go into the primary sensing area region when the user is not utilizing the spectrum or

ii) Detection sensitive where the providers allocate the frequency in terms of mathematical calculations and provide the spectrum with minimum threshold value for detection

All this is done to reduce interference between the primary and the secondary users therefore the secondary user is allocated the spectrum based on a balance between these two constraints.

4.2.3 Development and evaluation of the sensing Device

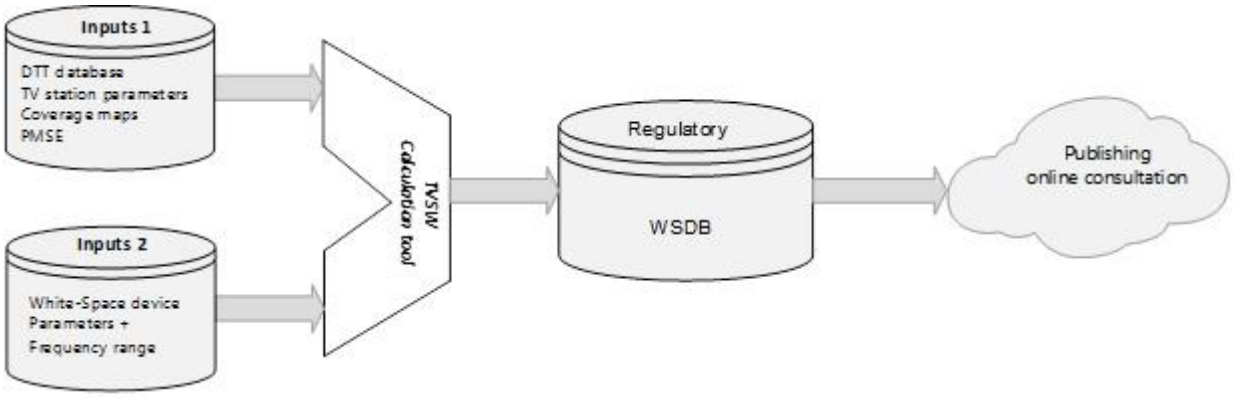

Figure 43: A model of data base development

4.2.3The TVSW Calculation Tool

A tool for radio planning will be required to calculate and do the estimation obtained from the database on the existence of DTT stations, the available channels on each point given in an area. The main idea for such a procedure is to protect these available transmitters (allotment and assignments) from any harmful interference on a strategy that is built on coverage and threshold calculation.

When this calculation is performed, the wanted data is passed to the backups to update the WSDBs in readiness for the next requests from WSD. The data input taken into account in this calculation involves, wireless sensing device (WSD) parameters, identification and frequency range.

Input data – this involves all the parameters that are needed for the calculations and for the determination of spectrum holes. This information consists of-

- PMSE transmitter's database and the DTT licensed and their site location, their transmission parameters and the coverage already calculated.
- The requests from the wireless sensing devices channels that have known transmission parameters such as dynamic range, frequency band and power.

Database for licensed station –this database has all the PMSE and the DTT already given out in a particular area and at a national level. Therefore, their characteristic such as coverage maps, protection ratios. Location, frequencies and radiated power for each transmitter that is licensed is available.

Database for the unlicensed wireless sensing device has the following data:-

- Coordinates from latitudes and longitudes or the Cartesian, spherical and cylindrical coordinates, aerial heights and the altitude of master WSD.
- Characteristics of antennae such as polarization, gain and power
- Class of the equipment
- The band of frequency or the channel that the WSD is able to operate.

All this will be stored in WSDB (data management tool) that is special and can be put on a dedicated website for the sharing of information on the availability of free channels that is controlled by the regulatory body.

4.2.4 Development and Evaluation of the Tool

Under the configured system, the DES task on the tool bar is operated and the statistics option selected. A tree topology is displayed displaying different statistics option. Under file transfer system chooses global statistics and click Ethernet. The system will display various parameters of the Ethernet to be tested click delay.

Under statistics, still move to wireless Lan advance and click delay. Now under this set parameters run the simulation for duration of one second see figure below:-

a) Case one: Transmitter and Receiving Device Delay Measurement

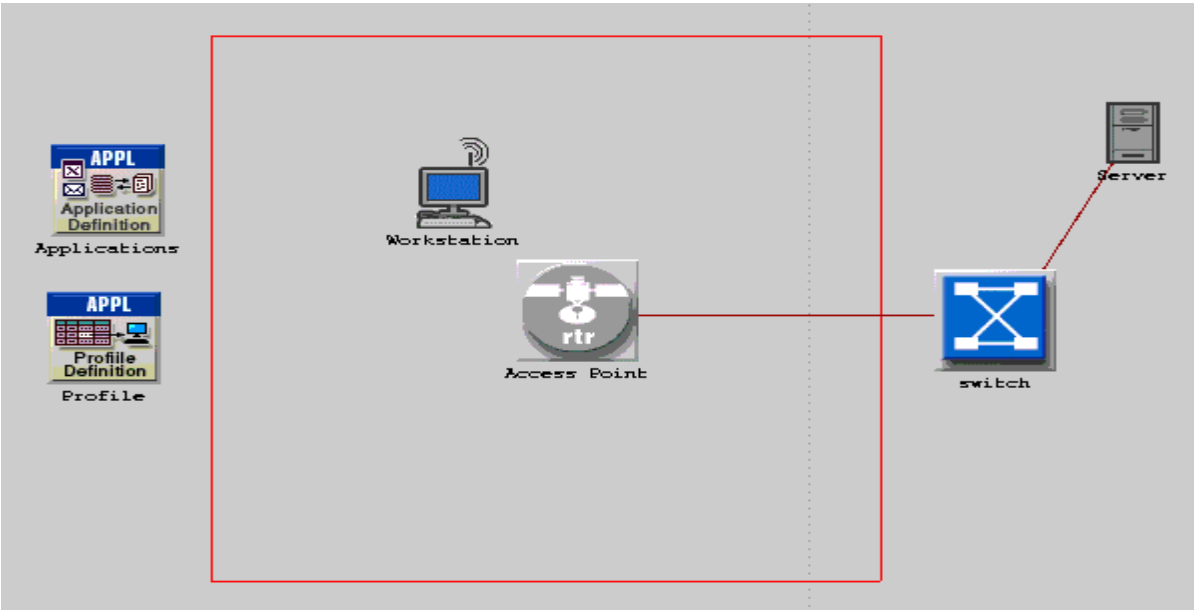

Figure 44: Set up for the measurement of delay

Results

A Graph is obtained as show below

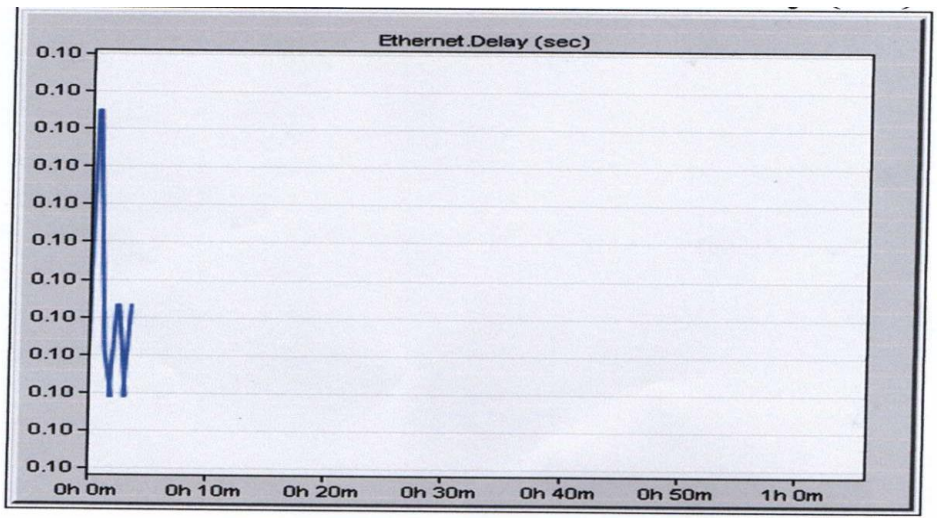

Figure 45: A graph of time delay variation

This shows that there is a constant delay over a very short time and after this even if the time is extended it will not affect the results

b) Case 2: Single Transmitter and Single Sensing Device

The scenario is to inspect and monitor the performance of one sensing device and one transmitter. Throughputs then analyzed for different application fed to the sensing devices gradually. Configuration is as follows:

Applications: FTP, with high load Applications fed gradually within 30mins interval the application is ran for duration of two hours.

Simulation Duration: 3.5 hours, Simulation Running Time: ~1min

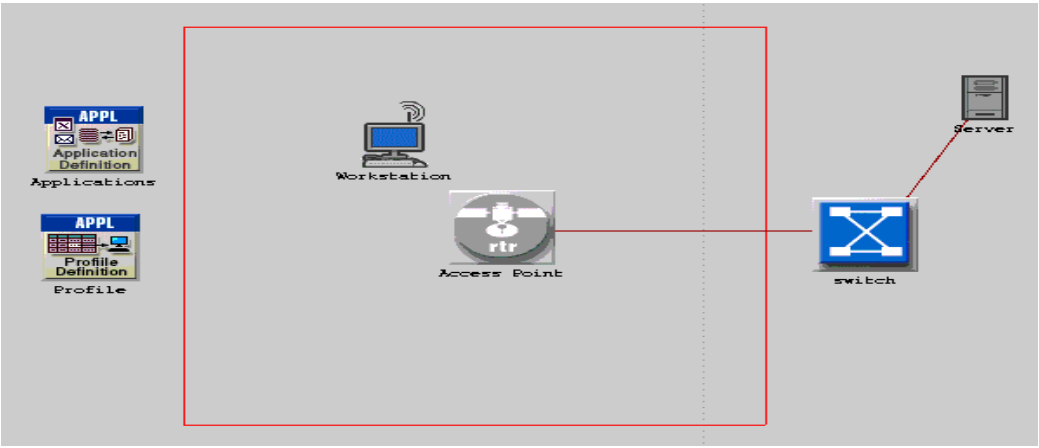

Figure 46: A set up to determine radio power received with distance

Results

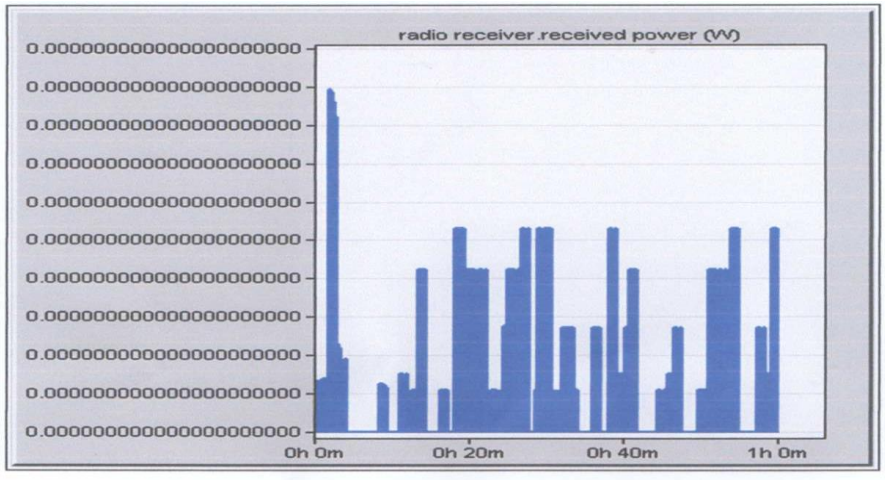

Figure 47: A graph showing the variation of received power with distance

C) Power of Moving the Sensing Device

The simulation of a sensing device from the AP (Transmitter) range moving towards the AP and moving away from the AP. The figure below shows this configuration and the route taken by moving the sensing device. The sensing device speed is 0.5m/s for a distance of 100meters.

Figure 48: Sensing power measurement

This is done through running a trajectory through the set experiment the results are as shown below:-

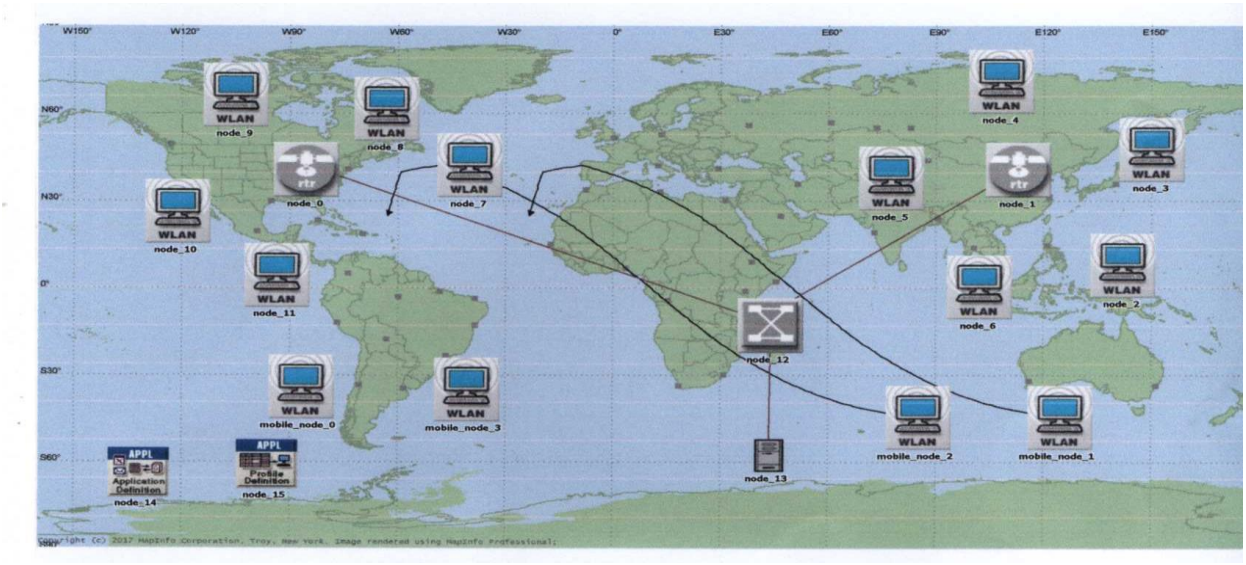

Figure 49: A set of a scenario to define a trajectory

Results

The sensing device power received is shown in the graph below. As the sensing device moves away from an optimum distance from the transmitter the power reduces and the device may be

prone to noise. It is observed that maximum power is received when the device is near the transmitter.

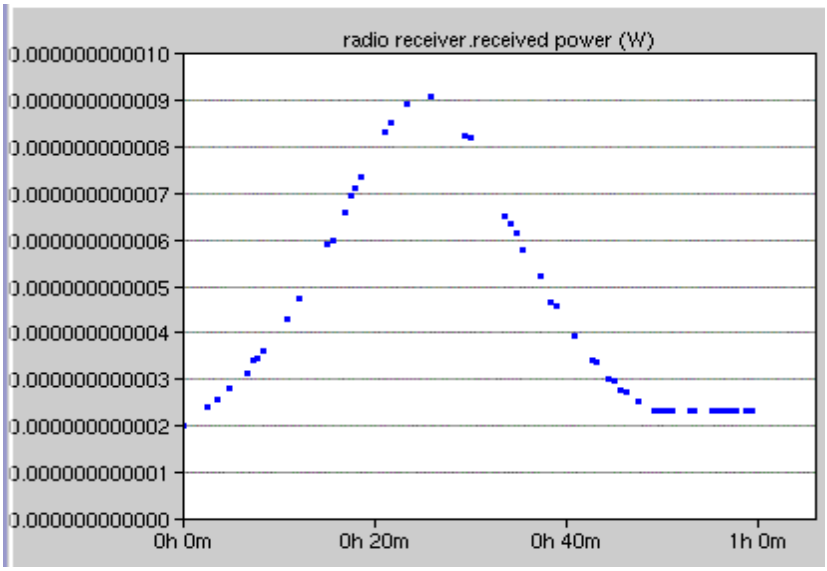

Figure 50: A graph showing the bandwidth of the receiver

d)Case 3 single transmitter and multiple sensing devices

The figure shows the performance of a multiple sensing on one area as compared to a single sensing device.

For a single transmitter with the same configuration and taking the transmitted data in packets the following results is obtained:

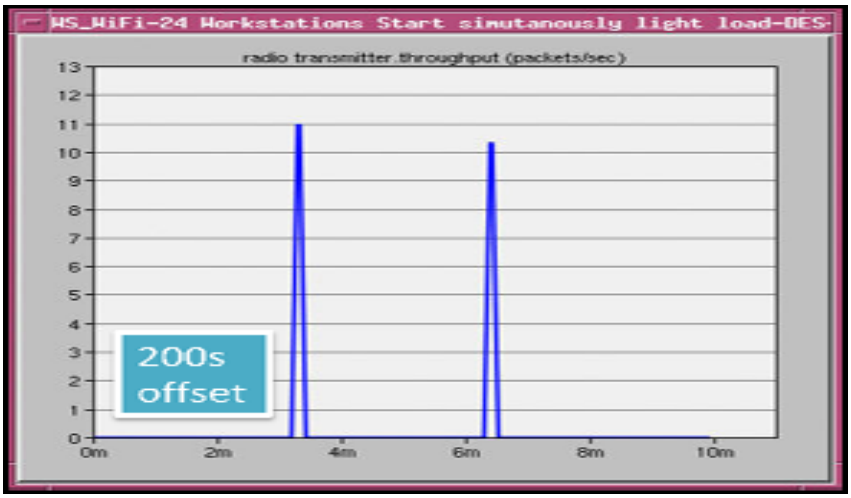

Figure 51: A graph of a single receiver pattern

For a multiple of sensors, the results are obtained as shown below:

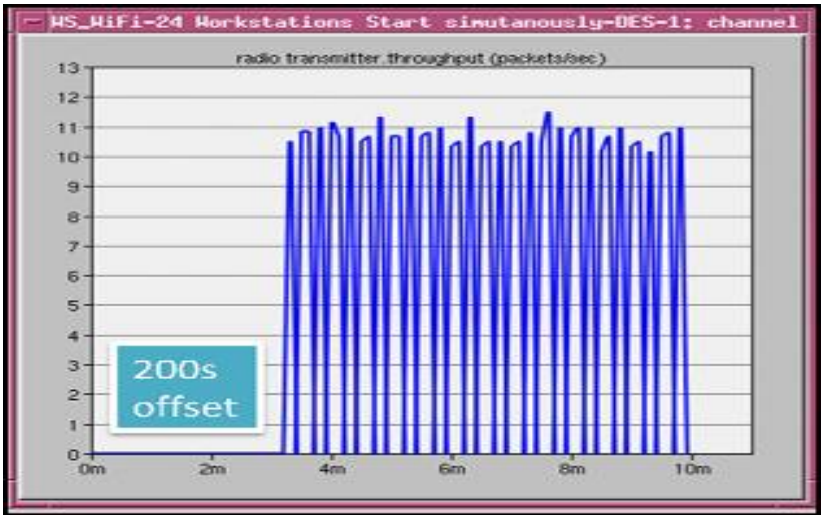

Figure 52: A graph of multiple receiver patterns

The results shows that if a number of receiving devices are allowed to receive or transmit the signals at the same time then interference is possible and therefore a measure is needed where by this interference can be suppressed.

CHAPTER FIVE: SUMMARY, CONCLUSION ANDRECOMMENDATIONS

5.1 Summary

Spectrum scarcity is caused by the congestion of the spectrum due to people having growing needs in wireless communication such as the explosion of the use of mobile communication in mobile telephone, internet service, e-learning, security and entertainment to mention but a few. Though there has been this growing demand the spectrum is still considered underutilized since studies have shown that this spectrum can still accommodate more usage if secondary transmission can still be accepted by the spectrum without harmful interference. The spectrum utilization can further be enhanced by having the regulation authorities easing there regulatory constraints, changing the ways of allocating channels from the spectrum and the use of modern wireless technologies that can operate in the spectrum without causing harmful interference to the protected primary user.

5.2 Conclusion

TV white space is one of the methods that can be used with wireless technologies to easy the problem of spectrum congestion if properly utilized. The white space are as a result of the gap that is occurring between two distinct channels that the regulating authorities use to control interference. Spectrum authorities assign allocations planned to be valid for a number of years or decades to come u and over special needs that are a number of years to come. This is done even though there might be urgent and useful need available in the next seconds.

When dealing with this problem ones eye is fixed on the problem to be arising from the regulating authorities that there is a problem in rigidity and spectrum planning but the problem extends further than this. When we use a static approach of allocating channels where wireless systems and other devices are particularly allowed to operate in certain allocated areas before they operate in the system then the regulatory authorities will be faced by another problem that is caused by the mobility and the lifespan of the changing wireless technology and their demand in the market.

The problem can be lessened by the use of allocating the spectrum by allocating it dynamically, that another user in demand can use when a person is not in use the spectrum. This introduces need of sensing the spectrum for the existence of the white spaces that can be allocated

dynamically. Therefore in conclusion is that wireless sensing device can be introduce that sense the spectrum dynamically and help to decongest the spectrum.

5.3 Recommendations for Future Work

i) This project depended much on simulation experiments and mostly in carrying simulation experiments various assumptions are made to come up with good results. In practical fields the reality is that such assumptions will not apply and therefore comes the need of testing the actual gadget on the field to try to improve the results.

ii) Simulation was done with opnet educational software that is inferior with the commercial opnet where other icons for wireless technologies such as transmitters are absent. To be able to come up with proper simulation commercial opnet should be purchased and utilized

iii) The design was done with a cognitive radio approach which suffers from detection sensitivity approach of using energy detection in that when it is sensing other device in its vicinity should be silent or otherwise would cause interference to reduce this problem the sensing device should be able to use a combination of detection method to allow other device to sense even if the master sensor is in progress.

5.4 Contributions

The research work done has contributed mostly to the analysis of the spectrum a reader can at least read and understand components of the spectrum. In addition to this suggestion on how the policies can be relaxed to accommodate other users (secondary) has been done. Lastly the analysis, and break down of the device that has been thoroughly explained can help a designer to come up with the actually gadget.

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