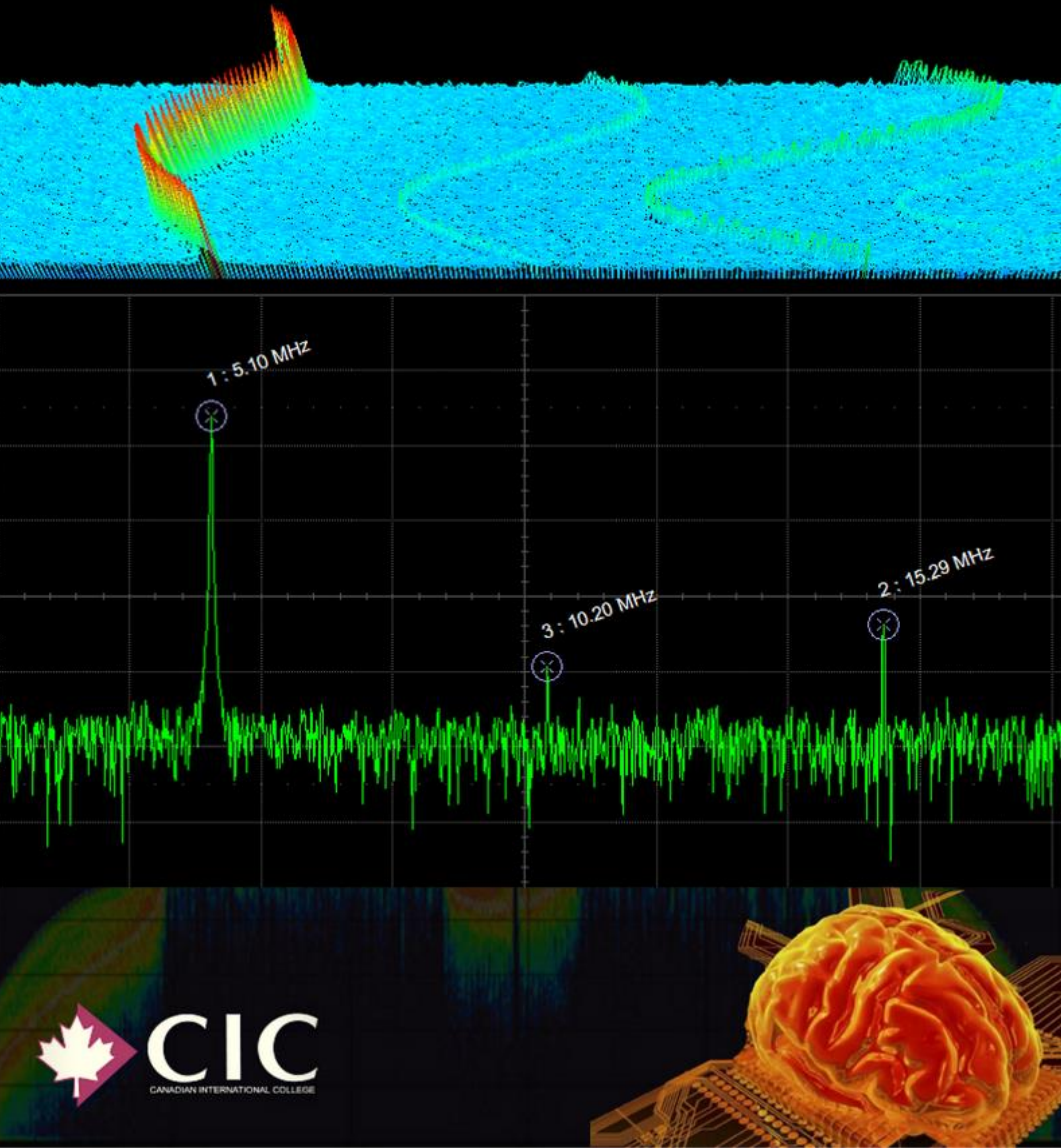
Graduation Project Report VER.1

CRN

Cognitive Radio Network



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Abstract

The Concept of Cognitive Radio (CR), was introduced to solve the spectrum scarcity by allowing a secondary (unlicensed) users to share the spectrum band with the primary (licensed) users. The spectrum sensing, spectrum sharing and spectrum management are the key roles of Cognitive Radio Network (CRN) , which provide a more efficient spectrum utilization embedding higher degree of intelligence in wireless systems so we can see a huge paradigm shift to all wireless technologies. The Cognitive Radios will be able to sense, learn and to be aware of the surrounding environment and adapt itself without being explicitly programmed. The Expected and proposed Scenario is the ability to design a Dynamic Spectrum Sensing, Access and Decision Algorithm using (C and python) for Software Defined Radio (SDRs), to enable them to behave as cognitive radio nodes/terminals.

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(CRN_2016)

List Of abbreviation

ADC	Analog to Digital Converted
AI	Artificial Intelligence
ANN	Artificial Neural Network
ASIC	Application-specific integrated circuit
CBR	Case Based Reasoning
CISC	Complex-instruction-set computer
CPU	Central Processing Unit
CR	Cognitive Radio
CRN	Cognitive Radio Network
CSS	Cooperation Spectrum Sensing
DAC	Digital to Analog Converter
DDC	Digital down converter
DSA	Dynamic Spectrum Access
DSP	Digital Signal Processing
DUC	Digital Up converter
ED	Energy Detection
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Array
FDMA	Frequency division multiple access
GNU	GNU's Not Unix
GPP	General Purpose Processor
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
ITU	International Telecommunication Union
MF	Matched Filter
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
MSP	Mixed Signal Processing
NTIA	National Telecommunications and Information Administration
NTRA	National Telecom Regulatory Authority
OFDMA	Orthogonal Frequency division multiple access
PSD	Power Spectral Density
PU	Primary User
R&D	Research and Development
RF	Radio Frequency
RISC	Reduced-instruction-set computer
SDR	Software Defined Radio
SDRF	Software Defined Radio Forum
SU	Secondary User
SoC	System on Chip
US	United States
WWW	World Wide Web
WWRF	Wireless World Research Forum
ICR	Ideal Cognitive Radio

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CHAPTER 1

cognitive radio Introduction

1.1 Radio Frequency:

The electromagnetic spectrum, and in particular the RF -Radio Frequency- portion, is rapidly becoming one the most valuable natural resources. Beyond the historic voice communications and increasingly dominant multimedia and data networking focus of this text, this spectrum is regularly used for a diverse array of applications, including radar for finding large and small objects (from airplanes in the sky, to obstacles in the vicinity of your automobile, to studs in the walls of your home), monitoring and sensing applications, and even cooking food in the microwave oven in your home, and also calling, texting and browsing the WWW is the most key rule under the radio Definitions which use the RF as a resource to diverse and exchange Data and information which technically are referred as waveforms. The radio frequency spectrum is a component of the overall electromagnetic spectrum that stretches from roughly zero to nearly 3 × 1027 Hz (cycles per second). In this broad range, the domain from roughly 10 kHz to 300 GHz is usually described as the radio frequency spectrum [1][2] (though interestingly this region includes the spectral regions described as sonic and ultrasonic on the low end as well as the microwave spectral region on the high end of the range).

Figure1.1 indicates the NTRA'S spectrum Allocation of EGYPT.

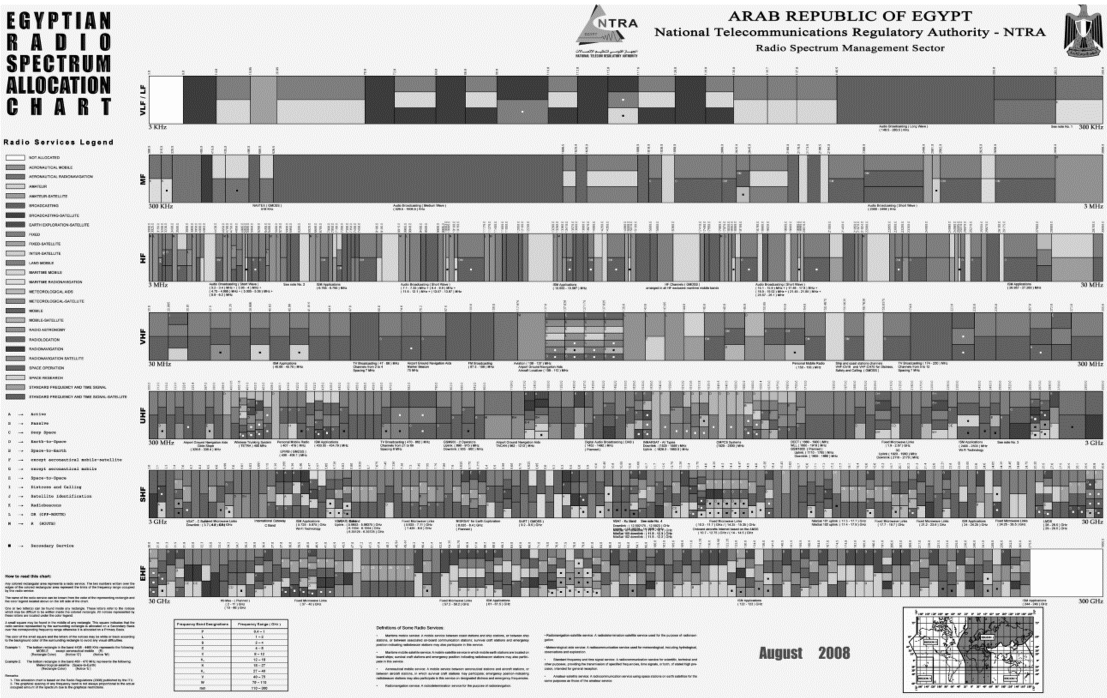


Figure1.1

As shown In figure The NTRA issued a frequency spectrum chart radio in April 2004. It highlights in a simplified way the allocation of radio services in Egypt on the frequency spectrum. This chart allocates 25 services over the frequency spectrum ranging from 9 kHz to 300 GHz by using distinct colors to provide an overview of the national radio frequency spectrum plan.

1.2 Problem Definition:

Networks touch every part of our lives, but managing such networks is problematic and costly. Networks need to be self-aware to govern themselves and provide resilient applications and services [3]. Self-awareness means that learning is a crucial component to reduce human intervention, and hence the need for biologically inspired or any complex learning approaches. While some of the existing breakthroughs in machine learning, reasoning techniques and biologically inspired systems can be applied to build cognitive behavior into networks, more innovations are needed. In the wireless space, the Industrial/Scientific/Medical (ISM) band has inspired impressive technologies, such as wireless local area networks, but interference is becoming increasingly problematic due to the overcrowding in this popular band. In addition, the cellular wireless market is in transition to data-centric services including high-speed Internet access, video, audio and gaming. While communications technology can meet the need for very high data link speeds, more spectrum is needed because the demand for additional bandwidth is continuously increasing due to existing and new services as well as users' population density. This calls for intelligent ways for managing the scarce spectrum.

1.2.1 Spectrum Utilization:

Capacity and data rates are the key role which enable the research and R&D to focus on cognitive radio. Users Need more capacity from the spectrum according to their needs. Historically major capacity gains obtained through frequency reuse, this trend will continue. Some examples on enhancing the spectrum, Smaller cells (femtocells) and better reuse, Remove the guards in multiple domains like OFDMA, Reduce the overprotection (better radios allowing less protection), Better channel awareness, better channel assignments, Better interference awareness , More interference allowance (partial overlapping) , DSA which aggregate the available links for wider bands for higher data rates, Better modulation/coding, MIMO, collaboration, cooperation, etc. for increasing spectrum efficiency, And Cognitive Radio comes as an evolution which acts as a main brain to find out new solution for the spectrum scarcity.

1.2.2 When Radio Meets software:

Cognitive radios can be understood as radios that gain awareness about their surroundings and adapt their behavior accordingly. For instance, a cognitive radio may determine an unused frequency band and use that for a transmission, before jumping to another unused band. The cognitive radio terminology was coined by Joseph Mitola and refers to a smart radio that has the ability to sense the external environment, learn from the history and make intelligent decisions to adjust its transmission parameters according to the current state of the environment [1]. Cognitive radio leverages the software defined radio (SDR), which offers a flexible configurable platform needed for cognitive radio implementation. Cognitive radio offers the potential to dramatically change the way spectrum is used in systems and increase the amount of spectrum available for wireless communications. Cognitive (wireless) networks are the future, and they are needed simply because they enable users to focus on things other than configuring and managing networks. Without cognitive networks, the pervasive computing vision calls for every consumer to be a network technician. The applications of cognitive networks enable the vision of pervasive computing, seamless mobility, ad hoc networks and dynamic spectrum allocation, among others.

1.2.3 Overview of The Cognitive Radio Network evolution:

Wireless services have moved well beyond the classical voice-centric cellular systems, and demand for wireless multimedia applications is continuously increasing. Access to radio spectrum is regulated either as licensed or unlicensed. In licensed spectrum, the rights to use specific spectrum bands are granted exclusively to an individual operator, and in unlicensed spectrum, certain bands are declared open for free use by any operator or individual following specific rules. This impressive success of unlicensed services has motivated the development of novel approaches to utilize unused spectrum in an intelligent, coordinated and opportunistic basis, without causing harm to existing services. For example, the US Federal Communications Commission (FCC) has already started working on dynamic spectrum access – whereby unlicensed users borrow spectrum from spectrum licensees. This is due to the fact that measurement studies have found that licensed spectrum is relatively unused across time and frequency [5], which may suggest that spectrum scarcity is artificial [6]. Cognitive radio is being considered as the enabling technology for dynamic spectrum access due to its ability to adapt operating parameters to changing requirements and conditions. The cognitive radio terminology was coined by Mitola [4] and refers to a smart radio which has the ability to sense the external environment, learn from the history and make intelligent decisions to adjust its transmission parameters according to the current state of the environment. Cognitive radios have recently received much attention for two reasons: flexibility and potential gains in spectral efficiency. They can rapidly upgrade, change their transmission protocols and schemes, listen to the spectrum as well as quickly adapt to different spectrum policies. Organizations have proposed methods that exploit cognitive radios to obtain higher spectral efficiency. They involve the concept of spectrum sharing, or secondary spectrum licensing. This is in contrast to current network operation where one licensee has exclusive access to a designated portion of the frequency spectrum. Under this model, much of the licensed spectrum remains unused. To alleviate this, proposals which involve cognitive radios sensing these gaps in the spectrum and opportunistically employing unused spectral holes have recently emerged [3].

1.2.4 A Glossary of Cognitive Radio Definitions

" The term "Cognitive Radio" evolved over time and now has several meanings in a variety of contexts"

"*Cognitive radio system (CRS)*: A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained." ***ITU Definition for cognitive radio*** [7].

A cognitive radio is, "a radio that can change its transmitter parameters based on interaction with the environment in which it operates." ***FCC Definition for cognitive radio*** [8].

"A radiocommunication system that is aware of its environment and internal state and can make decisions about, and adjust, its operating characteristics based on information and predefined objectives". ***NTIA Definition for cognitive radio*** [9].

Cognitive Radio employs a dynamic time-frequency-power based radio measurement and analysis of the RF environment, to make an optimum choice of carrier frequency and channel bandwidth to guide the transceiver in its end-to-end communication, with quality of service being an important design requirement. ***WWRF Definition for cognitive radio*** [10]

In total, they are mainly agreed that Any CR:

- Can autonomously exploit locally unused spectrum to provide new paths to spectrum access (spectrum aware)
- Can roam across borders and adjust themselves to stay in compliance with local regulations (policy aware)
- Can negotiate with several service providers (networks) to connect a user at the lowest cost (or optimal performance)- (network aware)
- Can adapt themselves and their emissions without user intervention (context and channel aware)
- Can understand and follow actions and choices taken by their users and over time learn to become more responsive and to anticipate their needs (user aware)

Figure1.2

CHAPTER 2

cognitive radio Architicture

2.1 Cognitive Radio Architecture:

Cognitive radio (CR) today includes a relatively wide range of technologies for making wireless systems have the ability to adapt and change their configuration parameters based on the channel/link reliability. In other words, to make them computationally intelligent have the ability to make new decision and find out answers for any give problem as we will discuss later. This has resulted from an interdisciplinary integration of complementary but somewhat isolated technologies: perception, planning and machine learning technologies from artificial intelligence on the one hand, and on the other hand software radio technologies that had come to include self-description in the extensible markup language, XML or configuration files CFG. The shown figure2.1 shows the main domains of Cognitive radio system which include the user domain, policy domain, Environmental and RF channel. The original visionary formulation of the ideal cognitive radio (iCR) remains underdeveloped: an autonomous agent that perceives the user's situation. the notion was extended to cognitive wireless networks (CWN) to diverse to include the whole network stack.

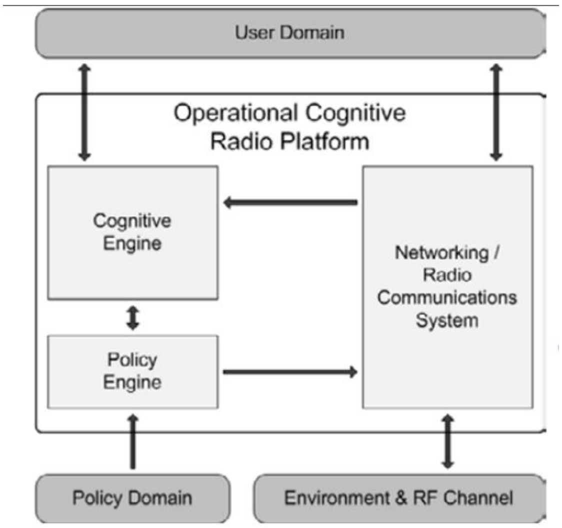


Figure2.1

The user domain tells the cognitive engine the performance requirements of services and applications. Service and application requirements are related to the QoS measures of a communications system. As each application requires different QoS concepts like speed and latency, the user's application may range from voice telephony, to data networking, to text messaging, to graphic display, to live video. Each application has its own unique set of requirements, which, in turn, translate into different implications on the performance requirements of the SDR this domain sets the performance goals of the radio. [11]

The external environment and RF channel provide environmental context to the radio's transmission and reception behavior. Different propagation environments cause changes in the performance of waveforms that correspond to optimal receiver architectures. A heavy multipath environment requires a more complex receiver than simple lineofsight propagation or lognormal fading. The external radio environment also plays a significant role in performance and adaptation. This environmental information helps provide optimization boundaries on the decisionmaking and waveform development.

Finally, ***the policy domain*** restricts the system to working within the boundaries and limitations set by the regulatory bodies as interpreted by the policy engine. The policy environment might determine a maximum amount of power a radio can use in a given spectrum or other spectrum rights with respect to other users, as was done in the 700MHz band recently auctioned by the FCC.The rules from the FCC and other regulatory bodies impose constraints on the optimization space.

''The shown figure2.2 include the cognitive controller and its main component''

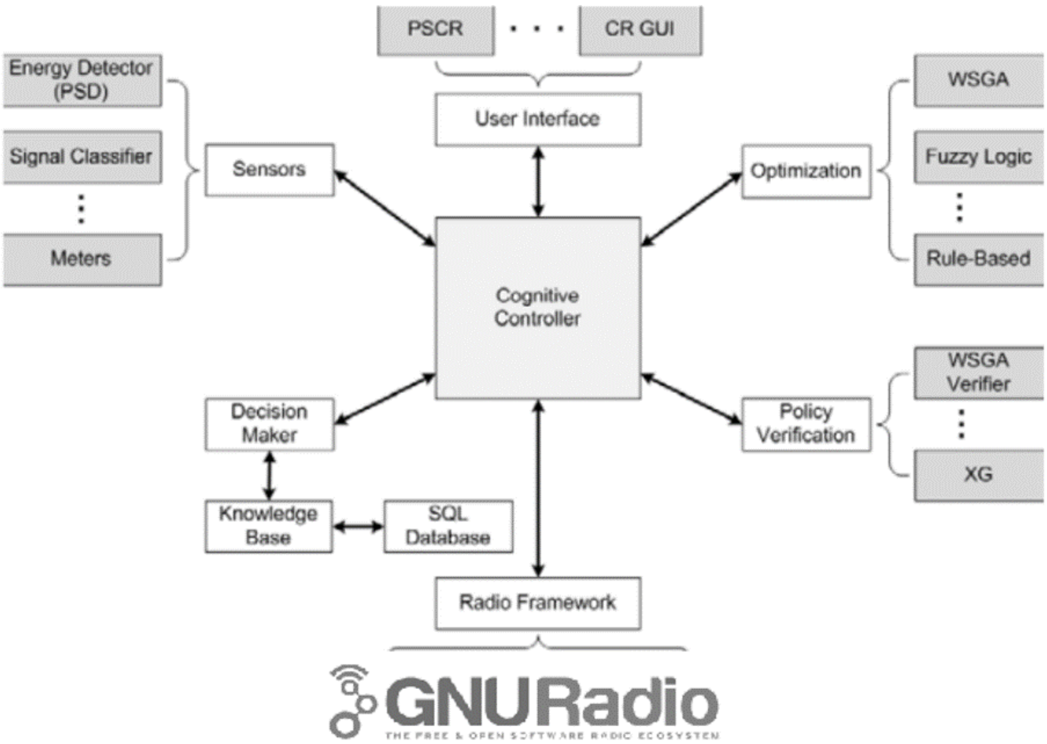


Figure2.2

cognitive controller: that acts as the system kernel and scheduler to handle the input/output and timing of the other attached components.

Sensors:..collect radio/environmental datafrom the radio or other systems to describe and model the environment. Environmental data can include almost anything that will help the radio adjust its behavior, including radio propagation, interference models (temperature), position and location, time, and possible visual cues. In whatever manner, the data is collected, the important aspect of a sensor is having a standard approach to how data is transferred to the cognitive controller.

Optimizer: given an objective and environment, create an optimized waveform based on advanced and complex learning techniques such as ANN, Fuzzy logic or CBR.

Decision Maker: coordinate information and decide how to optimize and act.

Policy Engine: enforce regulatory restrictions.
Radio Framework: communicate with the radio platform to enable new waveforms and pull information from the sensors.
User Interface: provide control and monitor support to the cognitive engine.

2.2 Cognitive Cycle:

The figure2.3 includes the proposed cognitive cycle where we sense the Radio Environment using some sensing techniques then the sensory Data are mapped into the learning model to find out the corresponding solution. After that the radio is dynamically reconfigured to the corresponding parameters like transmitted power, sampling rate, center frequency or the wave form. And if there is any new solution which is absolutely based on a new problem it shall be stored in the Data base and this process allow us to construct and build our system memory -learning by experience-.

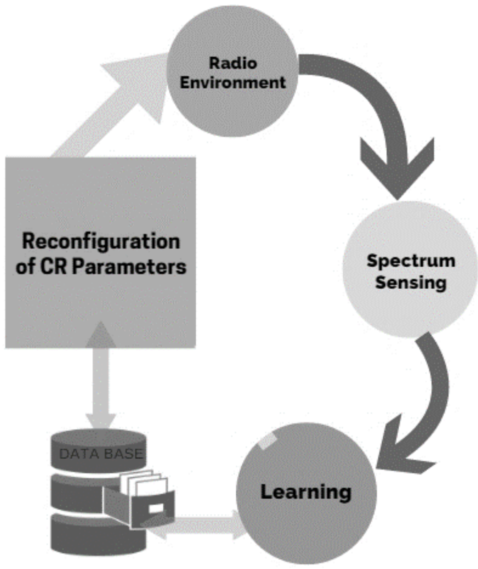


Figure2.3

2.3 Spectrum Sensing:

A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This technique is called spectrum sensing. Spectrum sensing and estimation is the first step to implement Cognitive Radio system [12][13].

We can categorize spectrum sensing techniques into direct method, which is considered as frequency domain approach, where the estimation is carried out directly from signal and indirect method, which is known as time domain approach, where the estimation is performed using autocorrelation of the signal.

Spectrum Sensing for Spectrum Opportunities: Spectrum Sensing Classifications:

a. Primary transmitter detection: In this case, the detection of primary users is performed based on the received signal at CR users. This approach includes matched filter (MF) based detection, energy based detection, covariance based detection, waveform based detection, cyclostationary based detection, radio identification based detection and random Hough Transform based detection.

b. Cooperative and collaborative detection: In this approach, the primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the spectrum load smoothing algorithm or external detection.

2.3.1 Energy Detection:

ED method senses the amount of energy in the signal received by the cognitive radio. It is a non-coherent Detection method (Does not Require any prior knowledge) that detects the primary signal based on the sensed energy. Due to its simplicity and no requirement on a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing.

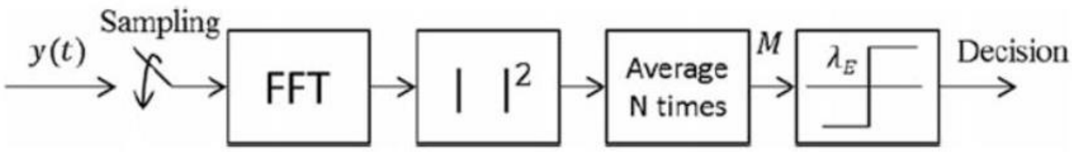


Figure2.4

The Block Diagram for Energy Detection technique is shown in Figure2.4 we can use sparse Fourier Transform but let's keep it simple using FFT which translates a signal from a time domain to a frequency domain representation. It can be thought of as a means of determining the power in each frequency of the signal resulting in what is known as the power spectral density of the received signal. This is essentially a plot of energy versus frequency for the range of frequencies contained in the received signal. If the power level is

deemed over a threshold value at a given frequency, then the presence of a primary user at that frequency is assumed. compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions.

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

$$y(k) = n(k) \ : Ho$$

$$y(k) = h * S(K) + n(k) \ : H1$$

Eqn2.1

Where y (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance σ2 and it could be presented as AWGN. Let y (k) be a sequence of received samples k Є {1, 2….N} at the signal detector, then a decision rule can be stated as,

$$Ho: \epsilon < v$$

$$H1: \epsilon > v$$

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

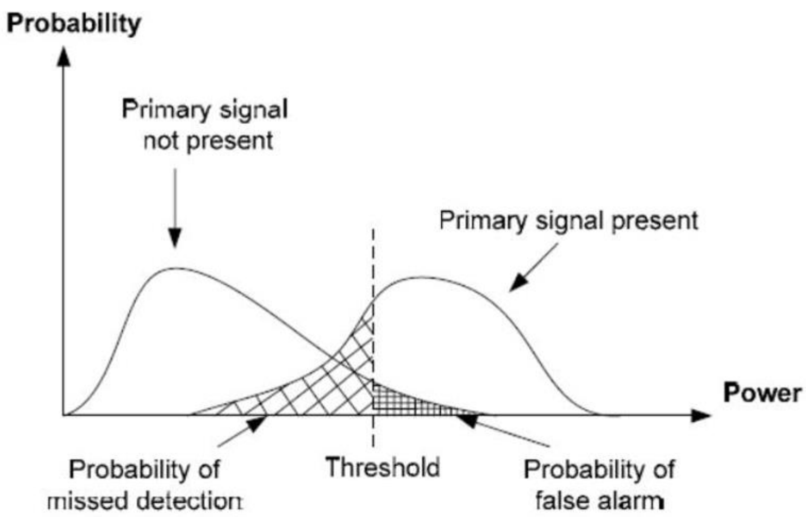


Figure2.5

Table2.1 Shows the four-binary hypothesis representation

Probability Statement	Decision	Statement
$P(Ho\|Ho)$	Correct	Noise Identified (spectrum hole)
$P(Ho\|H1)$	Incorrect	Missed Detection
$P(H1\|Ho)$	Incorrect	False Alarm
$P(H1\|H1)$	Correct	PU Signal Identified

Table2.1

However, ED is always accompanied by a number of disadvantages

i) sensing time taken to achieve a given probability of detection may be high.
ii) detection performance is subject to the uncertainty of noise power.
iii) ED cannot be used to distinguish primary signals from the CR user signals. As a result, CR users need to be tightly synchronized and refrained from the transmissions during an interval called Quiet Period in cooperative sensing.
iv) ED cannot be used to detect spread spectrum signals [14].

Coherent Techniques:

The energy detector issued when details of the primary user are not known and the idea is to perform a general check for activity levels. If details of the signals that are to be identified are known, then coherent techniques can be used, as opposed to the non-coherent energy detector technique. The terms coherent and non-coherent refer to the need for the receiver to synchronizes itself in frequency and phase with the transmitter. Coherency is needed to demodulate the received signal for analysis of its content. In communication systems, the transmitted signals are modulated, i.e. Some characteristic of the carrier wave is made to vary in accordance with information. Demodulation is the process by which the original signal is recovered from the wave produced by modulation. Achieving coherency requires extra complexity in the receiver. [15]

2.3.2 Cyclostationary Feature Extraction:

It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation as shown in figure2.5, which is not found in stationary noise and interference [19].

Thus, cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. Although it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is capable of distinguishing the CR transmissions from various types of PU signals. This eliminates the synchronization requirement of energy detection in cooperative sensing. Moreover, CR users may not be required to keep silent during cooperative sensing and thus improving the overall CR throughput. This method has its own shortcomings owing to its high computational complexity and long sensing time. Due to these issues, this detection method is less common than energy detection in cooperative sensing.

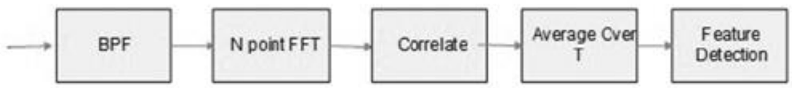


Figure2.6

2.3.3 Matched Filter:

A matched filter is obtained by correlating a known signal, or template, with an unknown signal to detect the presence of the template in the unknown signal. In this case the unknown signal is the signal received by the cognitive radio. The known signal is the signal of the primary user. This means that the cognitive radio must know in advance what kind of primary user signals it wishes to detect. The cognitive radio in this case would store details of the primary user signals of interest in memory and compare these details with the received signal in an attempt to detect the presence of the primary user. The process of comparing the received signal with the known signal or, more correctly stated, the process of correlating the received signal with the known template involves, as mentioned already, the demodulation of the received signal. The stored details of the primary user signal can help with the demodulation process. However, a lot of effort is needed to achieve coherency with the primary user signal, in order to actually carry out the demodulation. There are many techniques that can be used to achieve coherency that make use of, for example, pilots, preambles, synchronization words or spreading codes in the primary signal. So, while the need for coherency has implications for the complexity of the receiver, coherent detection is possible.

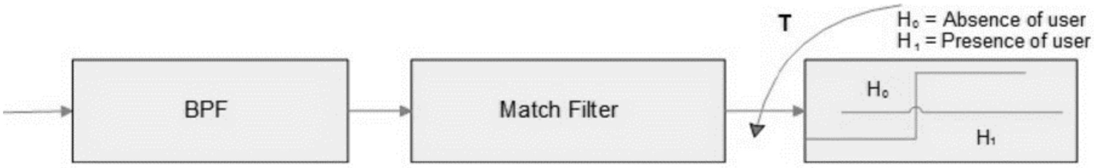


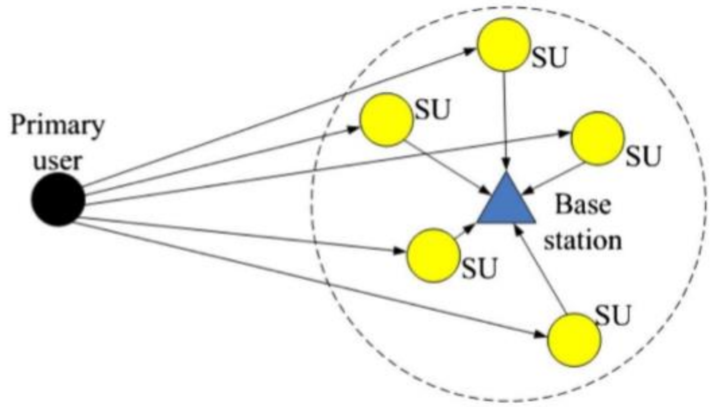
Figure2.7

2.3.4 Cooperative Spectrum Sensing-CSS-:

High sensitivity requirements on the cognitive user can be alleviated if multiple CR users cooperate in sensing the channel.

Centralized Coordinated Techniques: In such networks, an infrastructure deployment is assumed for the CR users. One CR that detects the presence of a primary transmitter or receiver, informs a CR controller which can be a wired immobile device or another CR user. The CR controller notifies all the CR users in its range by means of a broadcast control message. Centralized schemes can be further classified according to their level of cooperation as: Partially cooperative where network nodes cooperate only in sensing the channel. CR users independently detect the channel and inform the CR controller which then notifies all the CR users; and totally cooperative Schemes where nodes cooperate in relaying each other's information in addition to cooperatively sensing the channel [16].

Figure2.8



We consider a CR network composed of K SUs and a base station (fusion center), as shown in Figurer2.8. We assume that each SU performs energy detection independently and then sends the local decision to the base station, which will fuse all available local decision information to infer the absence or presence of the PU.

$$y = \sum_{i=1}^{k} Di \geq k \quad : H1;$$

$$y = \sum_{i=1}^{k} Di < k \quad : Ho;$$

Eqn2.2

From eqn2.2 where H0 and H1 denote the decision made by the base station that the PU is present or absent, respectively. The threshold k is an integer, representing the "n-out-of-K" rule. It can be seen that the OR rule corresponds to the case of k = 1, the AND rule corresponds to the case of k = K, and in the VOTING rule k is equal to the minimal integer larger than K

2.4.1 Sensing the Outside World:

In Order to learn we need sensors to observe the outside world. Then those sensors communicate directly to the controller who acts and decides based on it is core the cognitive engine which include the learning technique to enable the radio to act in intelligence way. The sensors are represented as the RF front Ends which have the capabilities to sense a wide or a narrow of a certain frequency band. The Signals/Data then shall be acquired (Amplified and Digitized) so mainly Data shall be received via the RF front end and then interface it to the Digital Back end for processing. Now the sensing peripherals key roles are done. The Data are then passed to some kind of Artificial/cognitive Engine which is mainly handle the data to Learn, Adapt and Making the proper decision. This branch of AI is called Machine Learning. **Where Machine Learning**: “Computational Learning using some kind of enhanced algorithm to learn and make predictions on data”

2.4.2 Technical Approach to the Cognition:

Cognitive radios are aware of their environment and intelligently adapt their performance to the user’s needs. A CR is a software defined radio with a “cognitive engine” brain. Conceptually, the cognitive engine responds to the operator’s commands by configuring the radio for whatever combinations of waveform, protocol, operating frequency, and networking are required. It monitors its own performance continuously, reading the radio’s outputs to determine the RF environment, channel conditions, link performance, etc., and adjusting the radio’s settings to deliver the needed quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints. We call these processes “reading the radio’s meters” and “turning the radio’s knobs".
The interaction as shown in figure2.9 between the cognitive engine and the radio through its knobs and meters. In cognitive radio terms, the waveform is the wireless signal transmitted that represents the current settings of all of the radio’s knobs.
Meters represent the metrics used in the radio optimization. Knobs include the type of modulation and modulation parameters, frequency channel, symbol rate, and channel and source coding. Meters include bit error rate (BER), frame error rate (FER), signal power, battery life, and computational resources.

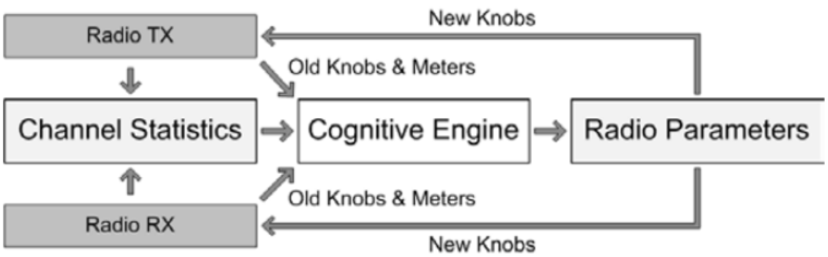


Figure2.9

<u>So briefly, cognitive radio uses the meters to build an understanding of the environment so as to adjust the knobs to improve the communications.</u>

2.4.3 A closer Look to AI:

One particularly successful method to solve the multi objective cognitive radio problems is the implementation of a highly flexible Machine Learning Algorithm which are the most known branch of Artificial Intelligence.
We Will discuss The AI and Machine Learning Algorithms.
e.g.: ANN, CBR and Genetic Algorithm

genetic algorithm. The operation of the genetic algorithm optimization system easily allows updates and additions to the optimization problem space as well as the dynamic creation of chromosomes to represent the waveform, and thus, it provides a solution independent of the search space and communications system.

As a way to augment the optimization process, we also introduce the use of case-based decision theory. This is a memory feedback system that learns and improves the cognitive radio behavior.

2.4.4 General Overview of Machine Learning Components:

Figure2.10

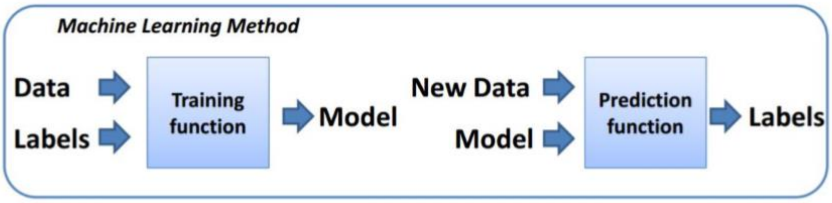


Figure2.11 shows how we construct a prediction model in Machine learning algorithm via 2 main functions which are Training function and prediction function.

Now we are going to handle and discuss the main components of ML:

Feature Extraction: Determining those components of the signal that are deemed most relevant to the application at hand including time domain analysis to extract features like the mean and variance and Frequency domain analysis to filter and reshaping the Data according to the application , determine the modulation scheme and estimate the frequency channel where a feature is a variable (predictor) believed to carry discriminating and characterizing information about the objects under consideration. We put those features into a vector where a Feature vector is A collection of d features, ordered in some meaningful way into a d-dimensional column vector, that represents the signature of the object to be identified. After Extracting the Features, we then shall classify them. A different between a bad and a good feature is shown in figure2.11

Figure2.11

Classification: Automated analysis of the features to determine what specific action should be taken based on the current values of the features, so it mainly assigns a class which is based on some patterns according to the extracted features as shown in figure2.12, in our case it shall determine if the primary user exists or not. Classification illustration is addressed below in fig where ω1=class0 and ω1=class1. So using Bayesian probability rule

$$p(x|\omega 0)\ \textit{is the class conditional probablity for class}0$$

$$p(x|\omega 1)\ \textit{is the class conditional probablity for class}1$$

$$\boxed{P(\omega_j \mid x) = \frac{p(x \mid \omega_j) \cdot P(\omega_j)}{p(x)}}$$

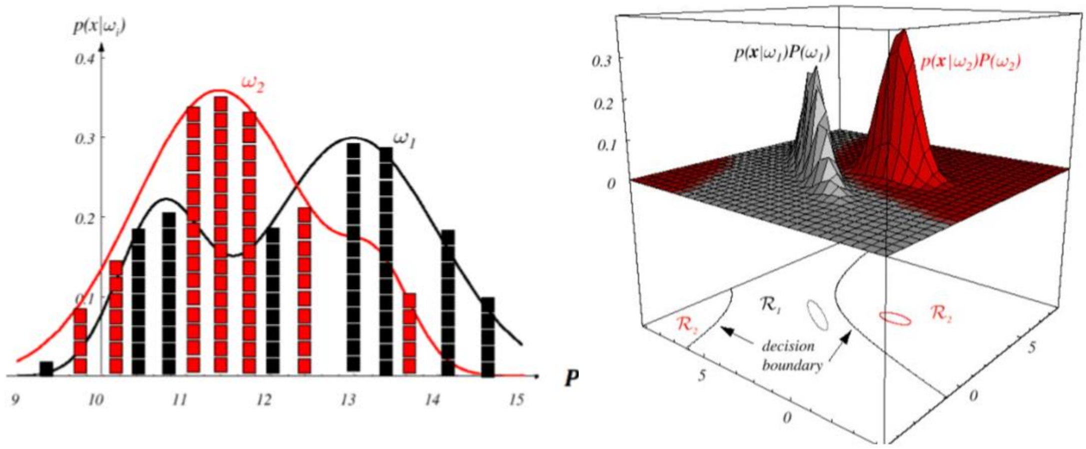


Figure2.12

Final step is **Feedback / Retraining:** Taking advantage of the cognitive plasticity of the algorithm to adjust to the new environment.

2.5 Machine learning Techniques:

Biologically Inspired Networking:

Biologically inspired networking is becoming a very active area of research simply because researchers are realizing that methods from biology have attractive features such as scalability and resilience to changes in the environment like Genetic Algorithm and ANN.

Genetic algorithm: The operation of the genetic algorithm optimization system easily allows updates and additions to the optimization problem space as well as the dynamic creation of chromosomes to represent the waveform, and thus, it provides a solution independent of the search space and communications system. As a way to augment the optimization process, we also introduce the use of case-based decision theory. This is a memory feedback system that learns and improves the cognitive radio behavior.

Artificial Neural Network: An Artificial Neural Network (ANN) is an information-processing paradigm that is inspired by the way biological nervous systems such as brain, process information [17]. ANN consists of multiple layers of simple processing elements called as neurons. The neuron performs two functions, namely, collection of inputs & generation of an output. Use of ANN provides overview of the theory, learning rules, and applications of the most important neural network models, definitions and style of Computation. The mathematical model of network throws the light on the concept of inputs, weights, summing function, activation function & outputs. Then ANN helps to decide the type of learning for adjustment of weights with change in parameters. Finally, the analysis of a system is completed by ANN implementation & ANN training & prediction quality.

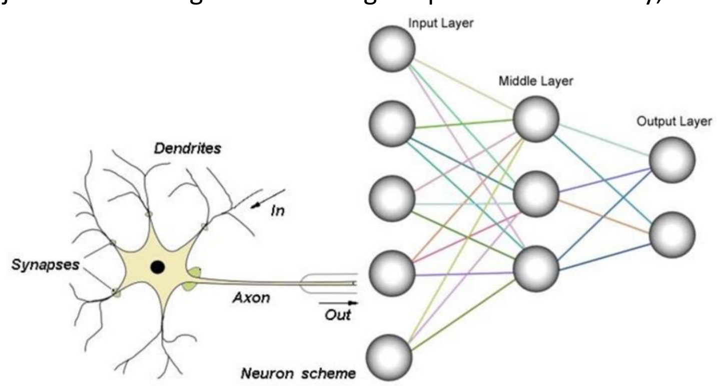


Figure2.13

Case-based reasoning refers to the reasoning process based on previous recorded experiences (cases). A case-based reasoner is an entity that performs case based reasoning. In general, CBR consists of case representation or case formulation, case selection and retrieval, case evaluation and adaptation, case learning and case database maintenance.

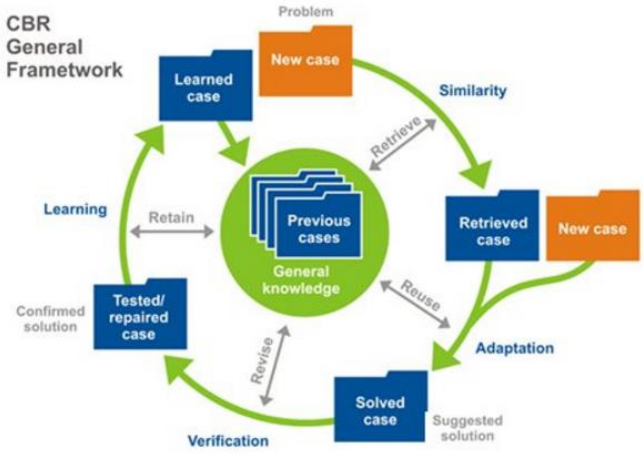


Figure 2.14

CHAPTER
3

PROPOSED TECHNICAL METHODOLOGIES

3.1 Software Defined Radio:

"Radio in which some or all of the physical layer functions are software defined"[18]

The SDR Forum, working in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) P1900.1 Def

First, we shall introduce What is meant by a Radio In a simple Definition:

A radio is any kind of device that wirelessly transmits or receives signals in the radio frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of information. In today's world, radios exist in a multitude of items such as cell phones, computers, car door openers, vehicles, and televisions which is implemented with a variety of standards like European mobile standards from GSM to Release 19, Wi-Fi, Bluetooth, GPS and there more. The control of radio functions by software algorithms embedded into the future “smart” communications device will directly affect the manner in which that device uses the spectrum.

The control of radio functions by software algorithms embedded into the future “smart” communications device will directly affect the manner in which that device uses the spectrum.

TI Definition:

Software-defined radio (SDR) is a radio communication technology that is based on software defined wireless communication protocols instead of hardwired implementations. In other words, frequency band, air interface protocol and functionality can be upgraded with software download and update instead of a complete hardware replacement. SDR provides an efficient and secure solution to the problem of building multi-mode, multi-band and multifunctional wireless communication devices. [19]

An SDR is capable of being re-programmed or reconfigured to operate with different waveforms and protocols through dynamic loading of new waveforms and protocols. These waveforms and protocols can contain a number of different parts, including modulation techniques, security and performance characteristics defined in software as part of the waveform itself.

3.1.1 The Need For SDR:

SDR (Software-Defined Radio) has revolutionized electronic systems for a variety of applications including communications, data acquisition and signal processing.

SDR Performs the majority of signal processing in the digital domain using programmable DSPs and hardware support, but some signal processing is still done in the analog domain, such as in the RF and IF circuits. The ultimate device, where the antenna is connected directly to an A-D/D-A converter and all signal processing is done digitally using fully programmable high speed DSPs. All functions, modes, applications, etc. can be reconfigured by software. Where it Is Flexible and Brings Analog and Digital World Together. Software defined radio (SDR) technology brings the flexibility, cost efficiency and power to drive communications forward, with wide-reaching benefits realized by service providers and product developers through to end users.

3.1.2 Benefits of SDR:

Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention. This results in higher production costs and minimal flexibility in supporting multiple waveform standards. By contrast, software defined radio technology provides an efficient and comparatively inexpensive solution to this problem, allowing multimode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades.

1. A family of radio "products" to be implemented using a common platform architecture, allowing new products to be more quickly introduced into the market.

2. Software to be reused across radio "products", reducing development costs dramatically
3. Over-the-air or other remote reprogramming, allowing "bug fixes" to occur while a radio is in service, thus reducing the time and costs associated with operation and maintenance.

4. New features and capabilities to be added to existing infrastructure without requiring major new capital expenditures, allowing service providers to quasi-future proof their networks.
5. The use of a common radio platform for multiple markets, significantly reducing logistical support and operating expenditures.

6. Remote software downloads, through which capacity can be increased, capability upgrades can be activated and new revenue generating features can be inserted.

7. Reduce costs in providing end-users with access to ubiquitous wireless communications – enabling them to communicate with whomever they need, whenever they need to and in whatever manner is appropriate.

MULTISTANDARDS IN ONLY ONE PLATFORM

3.1.3 SDR ARCHITECTURE:

SDR defines a collection of hardware and software technologies where some or all of the radio's operating functions (also referred to as physical layer processing) are implemented through modifiable software or firmware operating on programmable processing technologies. These devices include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) or other application specific programmable processors. The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring new hardware. But our target is FPGA where it meets the flexibility and efficiency and higher processing. *we shall here mention the difference between CPU, GPU, FPGA, ASIC. So we can easily manipulate its waveform The noun "radio" refers to the device used for transmitting and receiving RF signals. The term "wireless" refers to a method used for radio communications. A waveform is literally the shape of a signal (including, but not limited to radio signals). However, today the term “waveform” is used to describe the functionality being performed. SDR hardware can have many waveforms. Previously, it was a one-to-one relationship (for each desired waveform, an individual radio was required). Many Waveform functions can be performed within a single SDR system but not necessarily simultaneously. For some waveforms, the software must be modified “on-the-fly” to perform the different functions.

Component of SDR

The Block Diagram is shown in Figure3.1, 3.2 are handled below in more details

1- Antenna-RF Externals-l:

Antennas used over a wide frequency range will require an antenna tuner to optimize the voltage standing wave radio (VSWR) and corresponding radiation efficiency.
Each time the transceiver changes frequency, the antenna tuner will need to be informed of the new frequency.
It will either have a presorted table derived from a calibration process, and then adjust passive components to match the tuning recommendations of the table, or it will sense the VSWR and adapt the tuning elements until a minimum VSWR is attained
. VSWR stands for **Voltage Standing Wave Ratio**, and is also referred to as Standing Wave Ratio (SWR).

2- RF Front End:

The RF analog front-end amplifies and then converts the radio carrier frequency of a signal of interest down to a low IF so that the receive signal can be digitized by an analog-to-digital converter (ADC), and then processed by a DSP to perform the modem function.

Similarly, the transmitter consists of the modem producing a digital representation of the signal to be transmitted, and then a digital-to-analog converter (DAC) process produces a baseband or IF representation of the signal. That signal is then frequency shifted to the intended carrier frequency, amplified to a power level appropriate to close the communication link over the intended range, and delivered to the antenna.

3- Basic digital hardware options:

There are a number of standard digital hardware options that can be used in a cognitive radio. In choosing a platform, we are typically interested in three features, namely flexibility, performance and power consumption Flexibility is a key factor in cognitive radio as radios must reconfigure themselves in order to suit prevailing conditions or user demands, etc. Different kinds of cognitive radio and different designs may call for different levels of flexibility. Performance relates to speed. Some tasks, such as heavy-duty signal processing, for example, may require exceptionally high speeds for execution and may not be implementable on slower platforms. Power consumption is very important in handheld devices but is becoming increasingly important in terms of sustainability and the environment. In the following sections six different hardware platforms for digital processing are briefly described. The descriptions are followed by an analysis of the options from a flexibility, performance and power consumption perspective, which gives a good indication of the tradeoffs faced by the designer. *Below we describe the most important digital units.*

ASIC An ASIC is an application specific integrated circuit. An ASIC, as the name suggests, is a circuit designed for a specific application, as opposed to a general-purpose circuit, such as a microprocessor. An ASIC is highly optimized for the task at hand and hence can deliver good performance. It cannot be reconfigured. ASICs are low in cost, have high performance and low power consumption. There are many ASICs in mobile phones.

FPGA Afield-programmablegatearray(FPGA)isasemiconductordeviceconsisting of a logic layer and a configuration layer. The logic layer is an array of basic logic blocks, such as AND and XOR, or more complex logic functions like multipliers or memories. The configuration layer is a grid of programmable interconnects of the logic elements, which is used to implement a given algorithm. The designer implements a given algorithm by deciding how the blocks are connected. FPGAs enable a high degree of parallelism, i.e. all used logic blocks execute at the same time, rather than sequentially. Hence, they offer very good performance. The phrase 'field-programmable' highlights the fact that the FPGA's function is defined by a user's program, i.e. is programmed in the field, rather than by the manufacturer of the device. Code can be loaded on to the FPGA's configuration memory to create the desired system. Traditionally the FPGA configuration is loaded from an external persistent memory (e.g. a PROM) at system startup and stays there for the full system lifecycle. Recent FPGAs allow dynamic partial reconfiguration, i.e. parts of the FPGA can be reconfigured while the remaining parts continue executing. Thus, functionality can be loaded on-demand, significantly increasing the device's flexibility and efficiency. However, the cost of flexibility is higher power consumption than the ASIC. FPGAs are often used in systems when new ideas are prototyped. They are used in base stations. WiMAX designs that use FPGAs are available.

DSP A digital signal processor is a microprocessor whose architecture is speciallydesignedfornumericalcomputationsondiscretenumbersequences specifically tailored to the processing of signals. A DSP is a programmable device, with its own native instruction code. This helps in the writing of code to implement the algorithms of interest. Once written the code can then be downloaded to the DSP chip. Though most general-purpose microprocessors and operating systems can execute DSP algorithm successfully, the specialized digital signal processor provides more optimized performance. The DSP core typically consists of an arithmetic logic unit, accumulator(s), multiple and accumulate (MAC) unit(s) and data and address busses. The multiply and accumulate operation ($a \leftarrow a+b*c$) is very common in DSP algorithms. The fact that DSPs cater for this explicitly makes them very suited to signal processing applications. Very many digital signal processing functions are needed in the Physical layer of a cognitive radio, making DSP chips attractive platforms. DSPs consume more power than FPGAs but tend not to be as fast. DSPs can be found in mobile phones GPU A graphics processing unit or GPU is a dedicated graphics rendering device. GPUs exist in many PCs and game consoles. Modern GPUs are very efficient at manipulating and displaying computer graphics, and their highly parallel structure makes them more effective than general purpose CPUs for a range of complex algorithms. A GPU can sit on top of a video card, or it can be integrated directly into the motherboard.

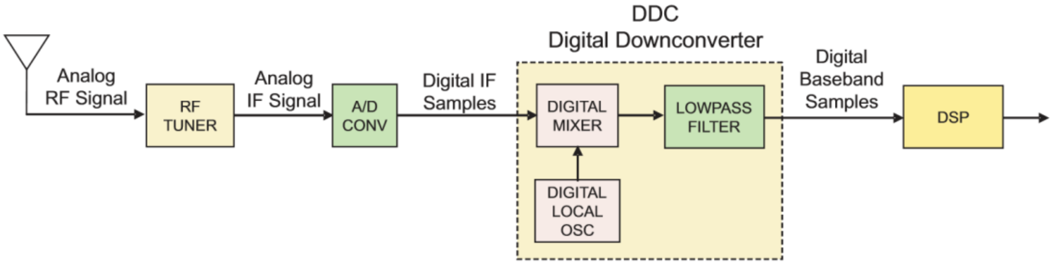


Figure3.1

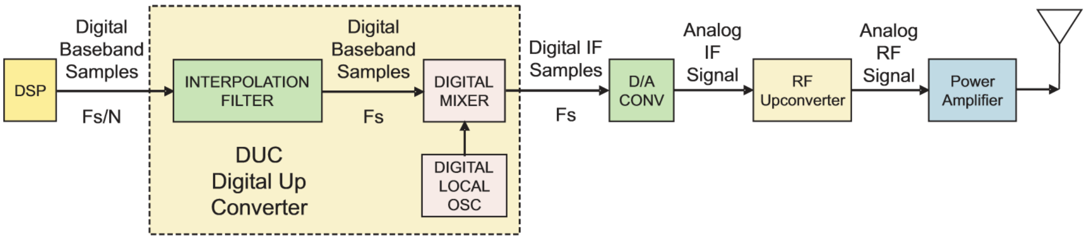


Figure3.2

3.2 GNU Radio Framework:

Before we start we shall know first what is a software radio?
software radio is a radio system which performs the required signal processing in software instead of using dedicated integrated circuits in hardware. The benefit is that since software can be easily replaced in the radio system, the same hardware can be used to create many kinds of radios for many different transmission standards; thus, one software radio can be used for a variety of applications!

GNU Radio is a free & open-source software development toolkit that provides signal processing blocks to implement software radios. It can be used with readily-available low-cost external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. It is widely used in hobbyist, academic and commercial environments to support both wireless communications research and real-world radio systems.

3.2.1 GNU Radio Function:

GNU Radio performs all the signal processing. You can use it to write applications to receive data out of digital streams or to push data into digital streams, which is then transmitted using hardware. GNU Radio has filters, channel codes, synchronization elements, equalizers, demodulators, vocoders, decoders, and many other elements (in the GNU Radio jargon, we call these elements blocks) which are typically found in radio systems. More importantly, it includes a method of connecting these blocks and then manages how data is passed from one block to another. Extending GNU Radio is also quite easy; if you find a specific block that is missing, you can quickly create and add it. Since GNU Radio is software, it can only handle digital data. Usually, complex baseband samples are the input data type for receivers and the output data type for transmitters. Analog hardware is then used to shift the signal to the desired center frequency. That requirement aside, any data type can be passed from one block to another – be it bits, bytes, vectors, bursts or more complex data types.

3.2.2 GNU Radio Function:

GNU Radio applications are primarily written using the Python programming language, while the supplied, performance-critical signal processing path is implemented in C++ using processor floating point extensions, where available. Thus, the developer is able to implement real-time, high-throughput radio systems in a simple-to-use, rapid-application-

Below in figure 3.3 is a simple flowgraph executed on GNU Radio platform which is mainly construct a source signal to view it in time domain and frequency domain

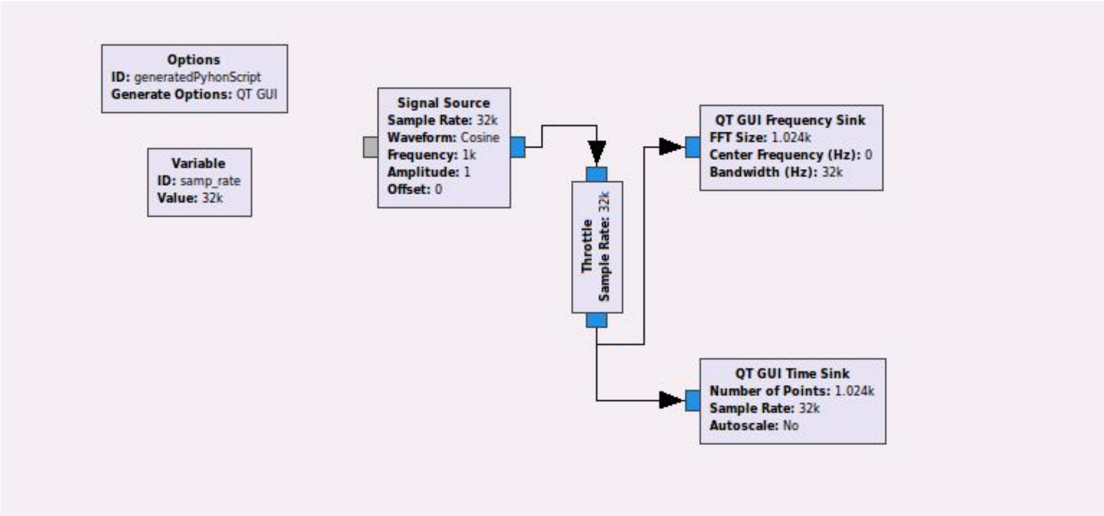


Figure 3.3

When we execute the flowgraph python file should be generated as shown in terminal in figure 3.4

```
Generating: '/home/astro/Desktop/generatedPyhonScript.py'
Executing: /usr/bin/python -u /home/astro/Desktop/generatedPyhonScript.py
Using Volk machine: avx_64_mmx_orc
```

Figure 3.4

What should be seen after execution shown if figure 3.5.

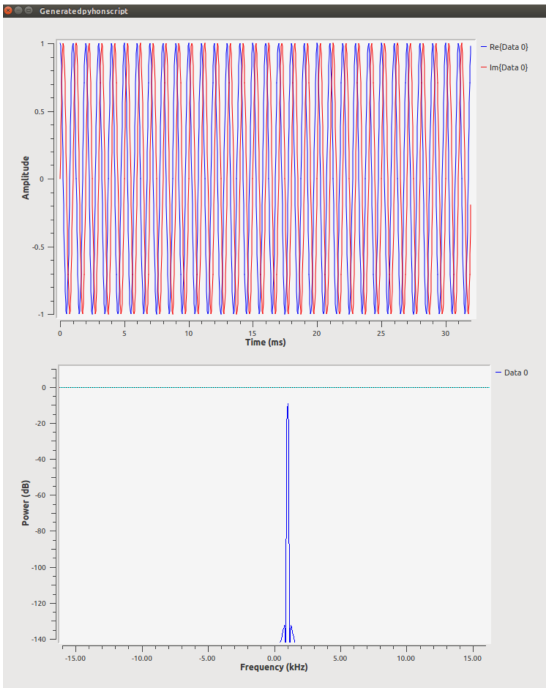


Figure3.5

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