WIDEBAND SPECTRUM SENSING USING SUB NYQUIST TECHNIQUES FOR COGNITIVE RADIO NETWORKS

A PROJECT REPORT

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In partial fulfilment of the award of the degree

Of

BACHELOR OF TECHNOLOGY
In
ELECTRONICS AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Faculty of Engineering and Technology ,
SRM Institute of Science and Technology
SRM Nagar, Kattankulathur – 603203, Kancheepuram District, Tamilnadu.

APRIL 2018

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Date: Internal Examiner External Examiner

DECLARATION

We here by declare that the Major Project entitled "WIDEBAND SPECTRUM SENSING USING SUBNYQUIST TECHNIQUES FOR COGNITIVE RADIO NETWORKS" to be submitted for the Degree of Bachelor of Technology is our original work as a team and the dissertation has not formed the basis for the award of any degree, diploma, associateship or fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any degree or diploma.

Place :

Date :

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ACKNOWLEDGEMENT

We would like to take this opportunity to thank the Director of Engineering and Technology, Dr. C. Muthamizchelvan and Head of Department of Electronics and Communication Engineering, Dr.T.Rama Rao, for the encouragement and support provided during the project. We would also like to thank Mrs.Shanthi Prince, Year Coordinator , who have been supporting pillar throughout and helped in the successful completion of the project.

We would like to express our deepest gratitude to our guide, Mr.M.Aravindan ,for his valuable guidance, consistent encouragement, personal caring, timely help and providing us with an excellent atmosphere for doing research. All through the work, in spite of his busy schedule, he has extended cheerful and cordial support to us for completing this research work. We would also like to thank our project coordinator Mrs. S.Latha for constantly evaluating the progress and providing changes required in implementing the project.

Also we would like to take this opportunity to thank all the faculty members and non teaching staff members in the Department of Electronics and Communication Engineering for their direct and indirect help rendered during the course of project work.

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ABSTRACT

Cognitive radio(CR) communications have recently emerged as a reliable and effective solution due to underutilization problem in the given radio spectrum. Nowadays Cognitive radio networks are extensively used because of their ability to produce reliable and efficient service. Spectrum sensing provides the essential information to enable this interweave communications in which primary and secondary users are not allowed to access the medium concurrently. In this project, we will be implementing a model that can be used to sense the unused RF bands by measuring their energy levels using power spectral density techniques.We will be using wideband sensing techniques that uses sub nyquist frequencies (frequencies that are below the Nyquist frequency). In this way we can detect the unused spectrum and hence reduce spectral wastage and improve spectral efficiency by accommodating the licensed secondary users.

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CHAPTER 1
INTRODUCTION

The electromagnetic radio frequency (RF) spectrum is a scarce natural resource, the use of which by transmitters and receivers is typically licensed by governments. Static spectrum access is the main policy for the current wireless communication technologies. Under this policy, fixed channels are assigned to licensed users or primary users (PUs) for exclusive use while unlicensed users or secondary users (SUs) are prohibited from accessing those channels even when they are unoccupied. Nowadays, it becomes obvious that this frequency allocation scheme cannot accommodate the constantly increasing demands of higher data rates. Cognitive radio (CR) has emerged as an innovative technology to solve this spectrum under-utilization problem in the next generation networks

1.1 COGNITIVE RADIO

The evolution in wireless communications has introduced new services and applications that require high data rates and a particular quality of service (QoS). This resulted in dramatically increasing demand on frequency spectrum to accommodate these new services or to enhance existing ones. However, frequency spectrum is characterized by static frequency allocation schemes that assign the existing frequency bands only to licensed users. This is the case despite that measurements indicate that the spectrum is underutilized by licensed users for significant periods of time. This aggravates spectrum scarcity and make it more difficult to accommodate the need for a greater spectrum. Therefore, the concept of cognitive radio (CR) is a promising technology to alleviate frequency spectrum scarcity and under-utilization by allowing unlicensed (secondary) users to access the spectrum when it is not being used by licensed users.

Cognitive radio is a system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.
This definition highlights the two main characteristics of cognitive radio, which are cognitive capability and reconfigurability. Cognitive capability enables CR devices to interact with the surrounding radio environment in a real-time manner and be aware of signal parameters such as waveform, RF spectrum, communication network type/protocols, geographical information, user needs and security policies, etc. CR devices then adjust their radio operating parameters according to the information sensed to achieve optimal performance. This is known as reconfigurability

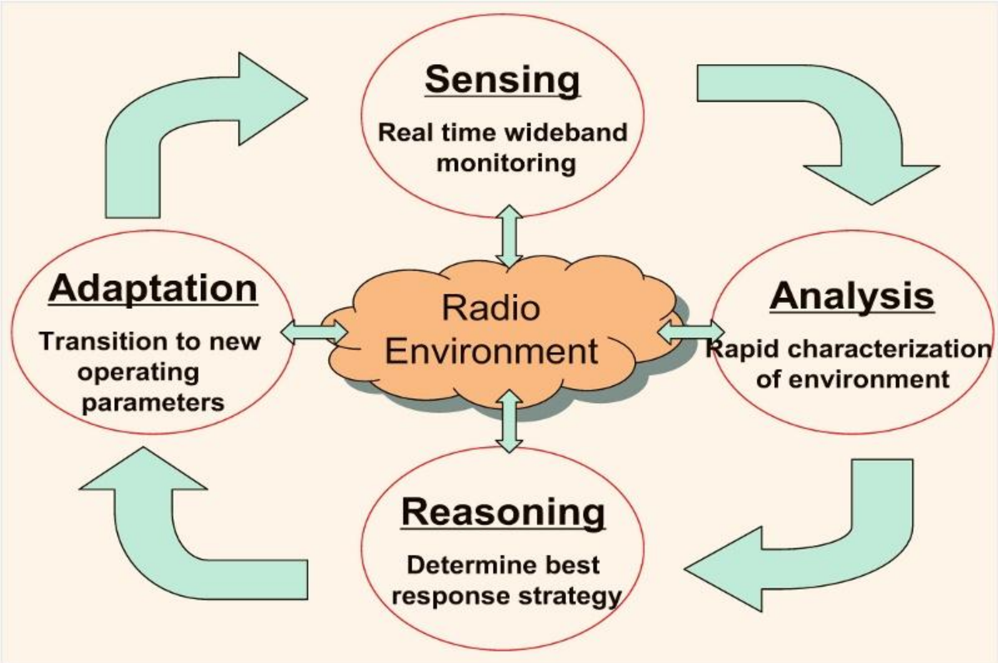

Figure 1 : Cognitive Radio cycle

In the spectrum sensing and analysis stage, CR detects spectrum holes, known as white spaces, for opportunistic access and spectrum utilization, it also senses PU activity to avoid causing harmful interferences due to SU transmissions. Then the characteristics of the frequency bands sensed such as their capacity and reliability are estimated and later used in decision making.

After that the spectrum management and handoff function allows the SU to choose the best frequency band, or hop among multiple bands to meet QoS requirements. For example, when the PU reclaims its band, then the SU transmitting in that band has to move to another available frequency band according to the channel capacity, path loss, holding time, etc.

The SU in cognitive radio networks may coexist in a certain frequency band with a PU or other SUs. Therefore, the need for efficient spectrum allocation and sharing mechanism is fundamental to protect the licensed PU from SU interference and to minimize the collisions and interference between SUs sharing the same frequency band.

CHAPTER 2
LITERATURE SURVEY

1)Tianyi Xiong, Hongbin LiPeihan Qi and Zan Li-"Pre-Decision for Wideband Spectrum Sensing with Sub-Nyquist Sampling"

Built on compressed sensing theories, sub-Nyquist spectrum sensing (SNSS) has emerged as a promising solution to the wideband spectrum sensing problem. However, most existing SNSS methods do not distinguish if primary users (PUs) are present or absent in the concerned spectrum band and directly pursue support recovery of the PUs. This may lead to a high false alarm rate and a waste of computational cost. To address the issue, we propose a pre-decision algorithm, referred to as the Pairwise Channel Energy Ratio (PCER) detector, to determine the presence or absence of PUs prior to signal support recovery. The proposed detector is based on the popular modulated wideband converter (MWC) framework for SNSS, which has several advantages over other SNSS approaches. The PCER test statistic is constructed from compressed samples obtained by the MWC. The decision threshold and the detection probability are derived in closed form following the Neyman Pearson criterion. Numerical results are presented to verify the theoretical calculation. The proposed PCER detection method is shown to be able to detect the existence of PUs in a wide range of signal-to-noise ratio (SNR) while being robust to noise uncertainty and does not need the prior knowledge of the PU signals. Additionally, our results show that the use of the PCER detector leads to a significant improvement of the correct support recovery rate of the PU signals.

2) Abdelmohsen Ali, Student Member, IEEE, and Walaa Hamouda, Senior Member, IEEE-" Advances on Spectrum Sensing for Cognitive Radio Networks: Theory and Applications

Due to the under-utilization problem of the allocated radio spectrum, cognitive radio (CR) communications have recently emerged as a reliable and effective solution. Among various network models, this survey paper focuses on the enabling techniques for interweave CR networks which have received great attention from standards perspective due to its reliability to achieve the required quality-of-service. Spectrum sensing provides the essential information to enable this interweave communications in which primary and secondary users are not allowed to access the medium concurrently. Several researchers have already considered various aspects to realize efficient techniques for spectrum sensing. In this direction, this survey paper provides a detailed review of the state-ofthe-art related to the application of spectrum sensing in CR communications. Starting with the basic principles and the main features of interweave communications, this paper provides a classification of the main approaches based on the radio parameters. Subsequently, we review the existing spectrum sensing works applied to different categories such as narrowband sensing, narrowband spectrum monitoring, wideband sensing, cooperative sensing, practical implementation considerations for various techniques, and the recent standards that rely on the interweave network model. Furthermore, we present the latest advances related to the implementation of the legacy spectrum sensing approaches. Finally, we conclude this survey paper with some suggested open research challenges and future directions for the CR networks in next generation Internet-of-Things applications.

3)Moshe Mishali and Yonina C. Eldar-" Wideband Spectrum Sensing at Sub-Nyquist Rates"

Sub-Nyquist systems capture the signal information in a different fashion than uniform high-rate samples. Consequently, digital processing, which is the prime reason for leaving the analog domain, becomes challenging. We propose a digital algorithm that translates samples obtained by the modulated wideband converter, a recent sub-Nyquist system, to the standard format of existing software packages. Our algorithm works in baseband, that is without the need to interpolate the samples to the Nyquist grid. Related methods such as non uniform sampling or the random demodulator are shown to lack the baseband processing option

4) **Wideband Spectrum Sensing for Cognitive Radio Networks: A Survey by Arumugam Nallanathan, King's College Of London Cheng-Xiang Wang, Heriot-Watt University and Yunfei Chen, University Of Warwick**

Cognitive radio has emerged as one of the most promising candidate solutions to improve spectrum utilization in next generation cellular networks. A crucial requirement for future cognitive radio networks is wideband spectrum sensing: secondary users reliably detect spectral opportunities across a wide frequency range. In this article, various wideband spectrum sensing algorithms are presented, together with a discussion of the pros and cons of each algorithm and the challenging issues. Special attention is paid to the use of sub-Nyquist techniques, including compressive sensing and multichannel subNyquist sampling techniques.

CHAPTER 3

SYSTEM ANALYSIS

3.1 Spectrum Sensing

Cognitive Radio being used in a number of applications, the area of spectrum sensing has become increasingly important. As Cognitive Radio technology is being used to provide a method of using the spectrum more efficiently, spectrum sensing is key to this application.

The ability of Cognitive Radio systems to access spare sections of the radio spectrum, and to keep monitoring the spectrum to ensure that the Cognitive Radio system does not cause any undue interference relies totally on the spectrum sensing elements of the system.

For the overall system to operate effectively and to provide the required improvement in spectrum efficiency, the Cognitive Radio spectrum sensing system must be able to effectively detect any other transmissions, identify what they are and inform the central processing unit within the Cognitive Radio so that the required action can be taken.

Cognitive Radio Spectrum Sensing basics

In many areas cognitive radio systems coexist with other radio systems, using the same spectrum but without causing undue interference. When sensing the spectrum occupancy, the cognitive radio system must accommodate a variety of considerations:

- **Continuous spectrum sensing:** It is necessary for the cognitive radio system to continuously sense the spectrum occupancy. Typically a cognitive radio system will utilise the spectrum on a non-interference basis to the primary user. Accordingly it is necessary for the Cognitive radio system to continuously sense the spectrum in case the primary user returns.
- **Monitor for alternative empty spectrum:** In case the primary user returns to the spectrum being used, the cognitive radio system must have alternative spectrum available to which it can switch should the need arise.
- **Monitor type of transmission:** It is necessary for the cognitive radio to sense the type of transmission being received. The cognitive radio system should be able to determine the type of transmission used by the primary user so that spurious transmissions and interference are ignored as well as transmissions made by the cognitive radio system itself.

Types of cognitive radio spectrum sensing

There are a number of ways in which cognitive radios are able to perform spectrum sensing. The ways in which cognitive radio spectrum sensing can be performed falls into one of two categories:

- **Non-cooperative spectrum sensing:** This form of spectrum sensing, occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is pre-loaded.
- **Cooperative spectrum sensing :** Within a cooperative cognitive radio spectrum sensing system, sensing will be undertaken by a number of different radios within a cognitive radio network. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit.

  Cognitive radio cooperation reduces problems of interference where a single cognitive radio cannot hear a primary user because of issues such as shading from the primary user, but a second primary user acting as a receiver may be able to hear both the primary user and the signal from the cognitive radio system.

Cognitive radio spectrum sensing methodologies

There are a number of attributes that must be incorporated into any cognitive radio spectrum sensing scheme. These ensure that the spectrum sensing is undertaken to meet the requirements for the particular applications. The methodology and attributes assigned to the spectrum sensing ensure that the cognitive radio system is able to avoid interference to other users while maintaining its own performance.

- **Spectrum sensing bandwidth:** There are a number of issues associated with the spectrum sensing bandwidth. The first is effectively the number of channels on which the system will sense whether they are occupied. By sensing channels apart from the one currently in use, the system will be able to build up a picture of alternative channels that can be used should the current one become occupied. Secondly the actual reception bandwidth needs to be determined. A narrow bandwidth will reduce the system noise floor and thereby improve the sensitivity, but it must also have a sufficiently wide bandwidth to detect the likely transmissions on the channel.
- **Transmission type sensing:** The system must be capable of identifying the transmission of the primary user for the channel. It must also identify transmissions of other units in the same system as itself. It should also be able to identify other types of transmission that may be spurious signals, etc.

- **Spectrum sensing accuracy:** The cognitive radio spectrum sensing mechanism must be able to detect any other signal levels accurately so that the number of false alarms is minimised.
- **Spectrum sensing timing windows:** It is necessary that the cognitive radio spectrum sensing methodology allows time slots when it does not transmit to enable the system to detect other signals. These must be accommodated within the frame format for the overall system.

Spectrum sensing instabilities

When developing a methodology it is necessary to ensure that the overall system remains stable. There are instances where levels of occupancy increase where cognitive radio systems will continually move from one channel to another. This considerably reduces the efficiency and at the worst case could almost render the system inoperable.

To illustrate the types of scenario that could be encountered, consider the case where channel occupancy is high and a limited number of channels are allocated or are available. The first cognitive radio system may have settled on a channel, but then detects another user so it moves to the next channel. This second channel may have been in use by another user which detects the new channel occupancy and moves. This could continue until the final user then moves into the first channel and the whole procedure repeats.

While it is possible that events may not occur in exactly this fashion, these types of scenario will occur and the cognitive radio spectrum sensing algorithms must be designed to take account of these forms of scenario, and ensure the optimum usage of the available spectrum.

Also with cognitive radio usage increasing, there will be an increase in signal frequency agility and signals will often appear on new frequencies. Accordingly this must be built into the decision algorithms to ensure that CR systems only move when it is necessary.

Cognitive radio spectrum sensing is one of the key algorithms associated with the whole field of cognitive radio. As experience grows, the cognitive radio spectrum sensing techniques will be refined and they will be designed to accommodate the increasing use of the spectrum as well as any malicious attacks that could be presented to CR systems.

3.2 Narrowband Spectrum Sensing

In narrowband sensing, conventional spectrum sensing techniques, discussed earlier in this chapter, and collaborative sensing techniques are used. This implies that the SU knows the frequency band over which sensing will be performed, i.e. the radio front-end starts with a tunable bandpass filter (BPF) that scans one frequency band at a time. TV broadcasting is an example of narrowband sensing, where the center frequency and bandwidth of each band are pre-defined and sensing is performed band by band.

There are different techniques to achieve spectrum sensing within narrow bands. The most effective and practical techniques are energy detection, matched filter detection and cyclostationary feature detection. Each technique has its advantages and drawbacks according to the followings.

A. Energy Detection

Energy detection is a non-coherent detection method that detects the primary signal based on the sensed energy. Energy detection is a sub-optional signal detection technique which has been extensively used in radiometry. The detection process can be performed in both time domain and frequency domain. To measure the signal power in a particular frequency band in time domain, a band-pass filter is applied to the target signal and the power of the signal samples is measured. To measure the signal power in frequency domain, the time domain signal is transformed to frequency domain using FFT and the combined signal power over all frequency bins in the target frequency band is then measured. Time domain energy detector consists of a low pass filter to reject out of band noise and adjacent signals. Implementation with Nyquist sampling A/D converter, square-law device and integrator. Frequency domain energy detector can be implemented similar to a spectrum analyzer by averaging frequency bins of a FFT. In energy detection method, the locations of the primary receivers are not known to the cognitive users because there is no signaling between the primary users and the cognitive users.

B. Matched Filter

Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of misdetection.

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

This technique has the advantage that it requires less detection time because it requires less time for higher processing gain. However, matched-filtering requires cognitive radio to demodulate received signals. Hence, it requires perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format. Moreover, since cognitive radio needs receivers for all signal types, the implementation complexity of sensing unit is impractically large. Another disadvantage of match filtering is large power consumption as various receiver algorithms need to be executed for detection. Further this technique is feasible only when licensed users are cooperating. Even in the best possible conditions, the results of matched filter technique are bound by the theoretical bound.

C. Cyclostationary Feature Detection

It has been introduced as a complex two dimensional signal processing technique for recognition of modulated signals in the presence of noise and interference. Cyclostationary feature detection exploits the periodicity in the received primary signal to identify the presence of PUs. The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences, or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference. 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.

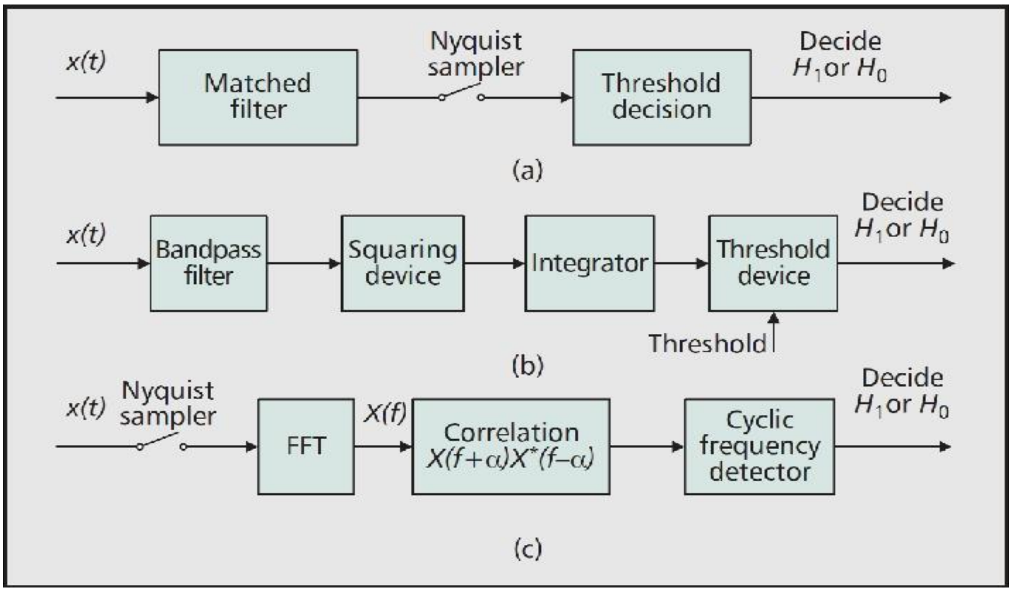

Figure 2 : a) Matched filter technique b)Energy Detection technique c)Cyclostationary feature detection technique

3.3 Wideband Spectrum Sensing

In wideband sensing, the entire band of interest is processed at once to find a free channel, with either a single Nyquist rate Analog-to-Digital Converter (ADC) or a bank of sub-Nyquist rate ADCs, both followed by digital processing. These typically consume a lot of power and radios with limited power budget cannot afford it. Wideband scanning could be performed via the following two different methods.

(1) By using a filter bank formed by preset multiple narrowband pass filters BPFs.This hardware-based solution requires more hardware components, thus increasing the cost and the RF impairments harmful effect, and limiting the flexibility of the radio by fixing the number of filters. After each filter, a narrowband state-of-the-art technique is implemented.
(2) By using sophisticated signal processing techniques. In fact, narrowband sensing techniques cannot be directly applied to scan a wideband since they are based on single binary decision for the whole spectrum. Thus, they cannot simultaneously identify vacant channels that lie within the wideband spectrum. Recently proposed wideband spectrum sensing can be broadly categorized into two types:

(i) **Nyquist wideband sensing** processes digital signals taken at or above the Nyquist rate.
(ii) **Sub-Nyquist wideband sensing** acquires signals using a sampling rate lower than Nyquist rate

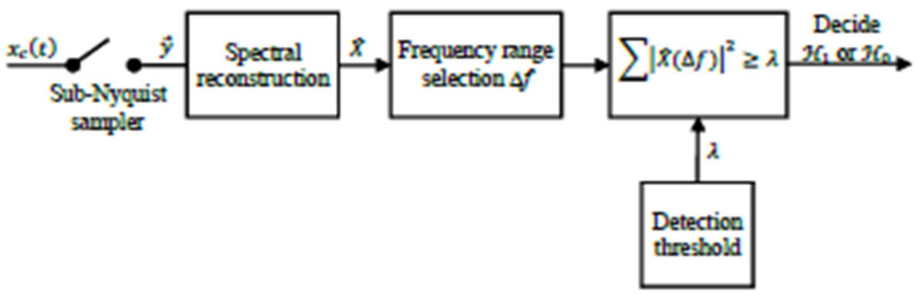

Figure 3 : Subnyquist wideband spectrum sensing

Challenges in Wideband Spectrum Sensing

In order to find a free channel quickly, the secondary radios should be able to process the entire band of interest all at once, which a paradigm needs shift from conventional narrowband sensing engines to wideband architectures. Then, challenges of wideband sensing can be analyzed in the following steps.

1) Latency and Complexity: In order to minimize the latency, the radios should adopt wideband architectures to search over multiple frequency channels all at once. It is also necessary for the secondary radios to be aware of the PU retransmission. Hence, sensing has to be repeated at certain intervals, which also demands for low-complexity techniques, which in turn will result in power saving. Realizing low-complexity wideband sensing techniques that can be afforded by sensor nodes is a challenging task.

2) Reliable Detection : Even though spectrum sharing radios allow secondary spectrum usage and co-existence with other technologies, protection of the PU from the harmful interference and minimizing degradation of the PU's performance due to this secondary radio link, always has the top priority. The interference to the PU due to the secondary radio link is often measured in terms of miss-detection probability (to detect a channel as free, when the channel is actually busy). The receiver that performs sensing could be affected due to multipath, fading and shadowing in the channel, or the PU could be hidden to the sensing receiver. These effects limit the detection performance and interfere with the PU. In addition to this, the receiver sensitivity plays a key role for a reliable detection. This becomes important especially while detecting nodes with lower transmit power. Receiver sensitivity decreases with an increase in the receiver bandwidth, as the receiver noise increases with the bandwidth ($N0 = -174 + 10 \log B + NF$, where N0 is the receiver noise power in dB, NF is the Noise Figure and B is the bandwidth in Hz). Achieving good receiver sensitivity with wideband architectures is relatively difficult.

3) Wideband RF Front-End: Designing a low-complexity wideband RF front-end is a challenging task and different approaches have been proposed in the literature. Multiple narrowband Band-Pass Filters (BFPs) could be employed to realize a filter bank, followed by a decision device to perform wideband sensing, but this architecture would require a large number of bulky components and the filter bandwidth of the BPFs (usually determined by the bank of capacitors) is preset. An alternative approach is to use a wideband Nyquist rate ADC, followed by digital processing. In order to achieve better sensitivity, the ADCs should have a higher dynamic range, which means a larger number of bits. Thus, wideband sensing requires high-rate and high resolution ADCs, which typically consume a lot of power. In case of sparse signals, the sampling rate can be relaxed and the acquisition can be done at a sub-Nyquist rate (significantly lower than the Nyquist rate). Later optimization algorithms can be used to recovery the signal without forgoing perfect reconstruction in the noiseless case. This is often referred to as a CS problem. However, current techniques demand signal recovery before detection.

3.4 BLOCK DIAGRAM

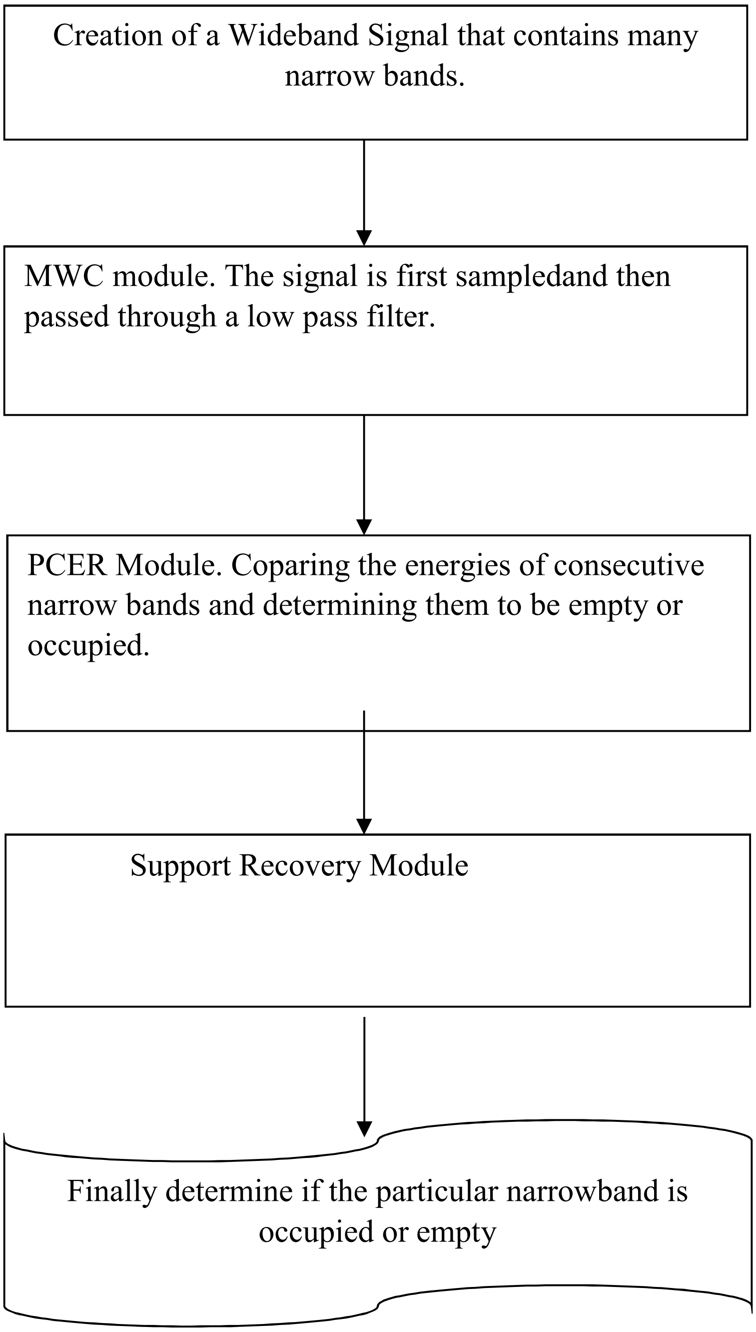

Figure 4 : Flowchart

CHAPTER 4

SYSTEM DESIGN AND METHODOLOGY

A pre-decision algorithm is designed, referred to as the Pairwise Channel Energy Ratio (PCER) detector, which is integrated with the MWC framework for SNSS. The PCER algorithm is to determine the presence/absence of PU signals prior to signal support recovery. Only if the PU signals are detected in the concerned frequency band will the function of signal support recovery be activated to estimate the location of the occupied bands; otherwise, signal support recovery is bypassed. It is necessary to point out that the proposed predecision algorithm can also be extended to other compressed sampling framework besides the MWC. We model this predecision problem as a binary hypothesis testing and construct a test statistic with compressed samples to detect the PU signals. By exploiting the statistical properties of the test statistic, we derive the decision threshold and the probability of detection in closed form, following the Neyman-Pearson criterion.

4.1 MODULES USED FOR SUBNYQUIST SPECTRUM SENSING :

- Modulated Wideband Converter
- Pairwise Channel Energy Ratio Detector
- Support Recovery Module

SNSS FRAMEWORK BLOCK DIAGRAM

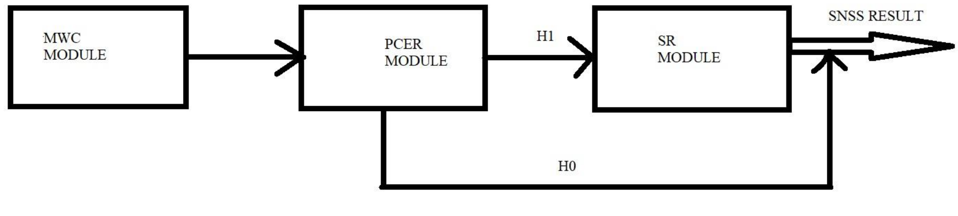

Figure 5: Subnyquist Spectrum Sensing Framework

MODULATED WIDEBAND CONVERTER

The modulated wideband converter (MWC) can blindly sample multiband analog signals at a low sub-Nyquist rate. The MWC first multiplies the analog signal by a bank of periodic waveforms. Then the product is low pass filtered and sampled uniformly at a low rate. The waveform period and the uniform rate can be made as low as the expected width of each band, which is orders of magnitude smaller than the Nyquist rate. Reconstruction relies on recent ideas developed in the context of analog compressed sensing, and is comprised of a digital step which recovers the spectral support. The MWC enables baseband processing, namely generating a low rate sequence corresponding to any information band of interest from the given samples, without going through the high Nyquist rate. In the broader context of Nyquist sampling, the MWC scheme has the potential to break through the bandwidth barrier of state-of-the-art analog conversion technologies such as interleaved converters.

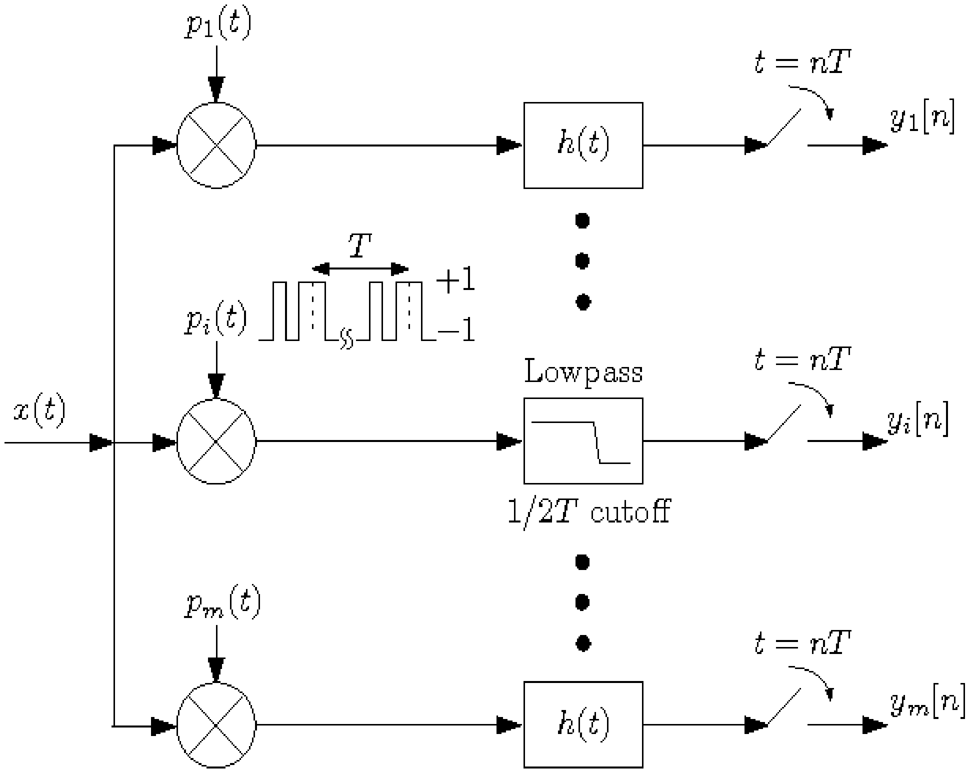

Figure 6 : Modulated Wideband Converter

PCER MODULE:

The PCER algorithm is to determine the presence/absence of PU signals prior to signal support recovery. Only if the PU signals are detected in the concerned frequency band will the function of signal support recovery be activated to estimate the location of the occupied bands; otherwise, signal support recovery is bypassed.

SUPPORT RECOVERY MODULE :

H0 denotes the hypothesis that there is only white noise in the input signal and H1 represents that there exist PU signals. If the detection result of the PCER module is H0, indicating that the whole frequency band is available and the support recovery is unnecessary and the SR module is bypassed. On the other hand if H1 is the hypothesis, then noise is present along with the signal and the Support Recovery Module is used.

4.2 BINARY DECISION TABLE

The probability of False Alarm is the probability of falsely detecting the Primary Signal when the primary user is actually silent in the scanned frequency band.

Probability of Detection is the Probability that the Primary User present in the specified band is correctly detected and the band is shown to be occupied.

		Hypothesis	
		PU present	PU not present
Wideband signal	PRIMARY USER PRESENT	Correct detection p(D)	Missed detection p(m)=1-p(D)
	EMPTY SPECTRUM	False Alarm p(FA)	Correct no detection p(null)=1-p(FA)

Table 1 : Binary Decision table

The Binary decision table shows the possible outcomes. This will determine the Probability of Detection , Probability of Missed Detection ,Probability of False Alarm.

4.3 RAYLEIGH FADING OF THE SIGNAL

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable. Rayleigh fading is a special case of two-wave with diffuse power (TWDP) fading.

4.4 AWGN Noise

Additive white Gaussian noise (AWGN) is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

- Additive because it is added to any noise that might be intrinsic to the information system.
- White refers to the idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.
- Gaussian because it has a normal distribution in the time domain with an average time domain value of zero.

4.5 RECEIVER OPERATING CHARACTERISITICS

In statistics, a **receiver operating characteristic curve**, i.e. **ROC curve**, is a graphical plot that illustrates the diagnostic ability of a binary classifier system as its discrimination threshold is varied.

The ROC curve is created by plotting the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings. The true-positive rate is also known as sensitivity, recall or probability of detection in machine learning.

The false-positive rate is also known as the fall-out or probability of false alarm and can be calculated as (1 − specificity). It can also be thought of as a plot of the Power as a function of the Type I Error of the decision rule (when the performance is calculated from just a sample of the population, it can be thought of as estimators of these quantities). The ROC curve is thus the sensitivity as a function of fall-out. In general, if the probability distributions for both detection and false alarm are known, the ROC curve can be generated by plotting the cumulative distribution function (area under the probability distribution from to the discrimination threshold) of the detection probability in the y-axis versus the cumulative distribution function of the false-alarm probability on the x-axis.

ROC analysis provides tools to select possibly optimal models and to discard suboptimal ones independently from (and prior to specifying) the cost context or the class distribution. ROC analysis is related in a direct and natural way to cost/benefit analysis of diagnostic decision making.

4.6 REALISTIC CONSTRAINT

Channel State Information (CSI)

In wireless communications, channel state information (CSI) refers to known channel properties of a communication link. This information describes how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance. The method is called Channel estimation. The CSI makes it possible to adapt transmissions to current channel conditions, which is crucial for achieving reliable communication with high data rates in multiantenna systems.

CSI needs to be estimated at the receiver and usually quantized and fed back to the transmitter (although reverse-link estimation is possible in TDD systems). Therefore, the transmitter and receiver can have different CSI. The CSI at the transmitter and the CSI at the receiver are sometimes referred to as CSIT and CSIR, respectively.

There are basically two levels of CSI, namely instantaneous CSI and statistical CSI.

Instantaneous CSI (or short-term CSI) means that the current channel conditions are known, which can be viewed as knowing the impulse response of a digital filter. This gives an opportunity to adapt the transmitted signal to the impulse response and thereby optimize the received signal for spatial multiplexing or to achieve low bit error rates.

Statistical CSI (or long-term CSI) means that a statistical characterization of the channel is known. This description can include, for example, the type of fading distribution, the average channel gain, the line-of-sight component, and the spatial correlation. As with instantaneous CSI, this information can be used for transmission optimization.

The CSI acquisition is practically limited by how fast the channel conditions are changing. In fast fading systems where channel conditions vary rapidly under the transmission of a single information symbol, only statistical CSI is reasonable. On the other hand, in slow fading systems instantaneous CSI can be estimated with reasonable accuracy and used for transmission adaptation for some time before being outdated.

In practical systems, the available CSI often lies in between these two levels; instantaneous CSI with some estimation/quantization error is combined with statistical information.

If the CSI is not known, then it is difficult to detect the presence or absence of Primary users in the channel.

4.7 ENGINEERING STANDARDS INVOLVED

4.7.1 GSM (IEEE 802.21)

GSM (Global System for Mobile communication) is a digital mobile telephony system that is widely used in Europe and other parts of the world. **GSM** uses a variation of time division multiple access (TDMA) and is the most widely used of the three digital wireless telephony technologies (TDMA, **GSM**, and CDMA)

4.7.2 WiMAX (IEEE 802.16e)

4G is the fourth generation of broadband cellular network technology, succeeding 3G. A 4G system must provide capabilities defined by ITU in IMT Advanced. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television.

4.8 MULTI-DISCIPLINARY COMPONENTS

MATLAB R2017a

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Input Signal with AWGN Noise

The input signal is taken and AWGN noise is added to it and then the input signal is plotted

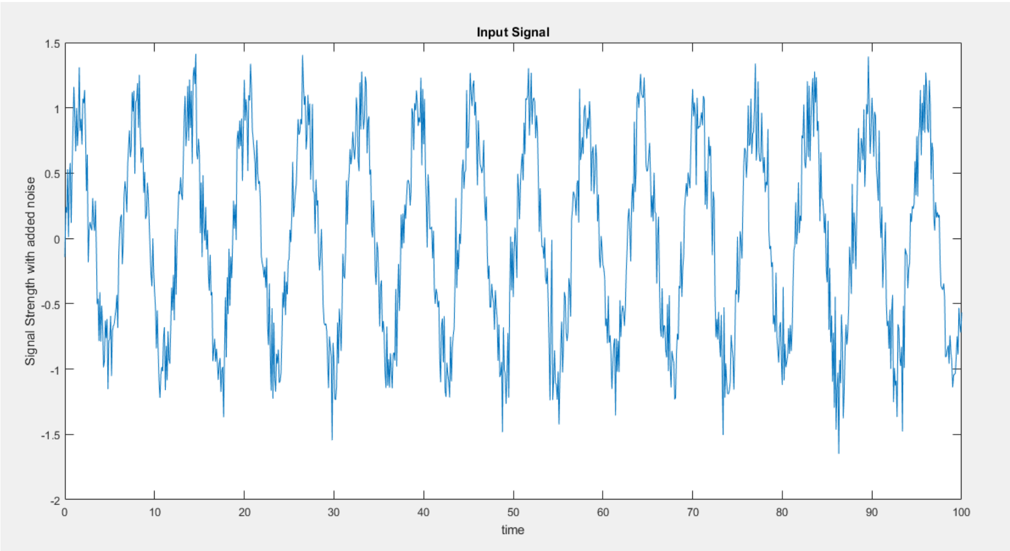

Figure 7 : Input signal with noise

5.2 Rayleigh Fading Envelope applied to input signal

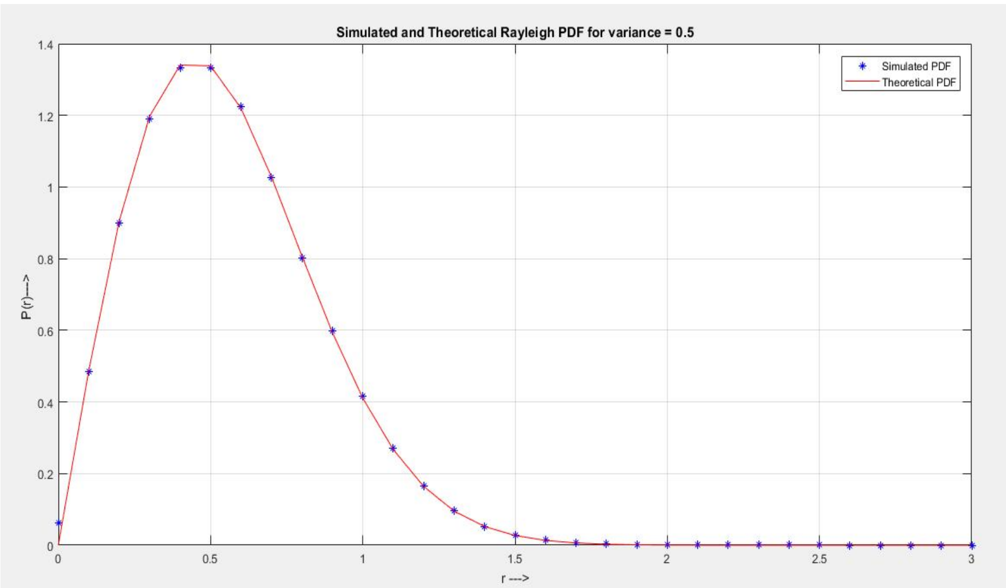

Figure 8: Rayleigh fading applied to input signal

The Rayleigh fading envelope is applied to the input signal and it has variance = 0.50.The red curve is obtained by considering the theoretical probability distribution function from the Rayleigh Fading equation.

r is the range of the signal

P(r) is the probability distribution function at range r

5.3 OPTIMIZATION IN WIDEBAND SPECTRUM SENSING IN COGNITIVE RADIO NETWORK.

Here local spectrum sensing technique is Energy Detection and the SNR=10dB and n=10 samples are used for this spectrum sensing. From figure 3(b) shown the threshold vs. total error rate using ED technique.

From figure 3(b), shows the total error probability versus threshold for different number of n=1, 2, 3, 4 ….10. We observe there are difference in the performance through using n=1 to 10.

Actually energy detection sets a threshold according to the noise and comparing with input of the energy detection data stream.. The ED mainly do the presence of a signal comparing the received energy with a known threshold derives the noise of signal

In this figure, we get the optimum value of 'n' out of 'K' CRs. We vary threshold value from 10 to 40.n=5 by modelling signifies that for that particular band there is an error every 5 seconds.

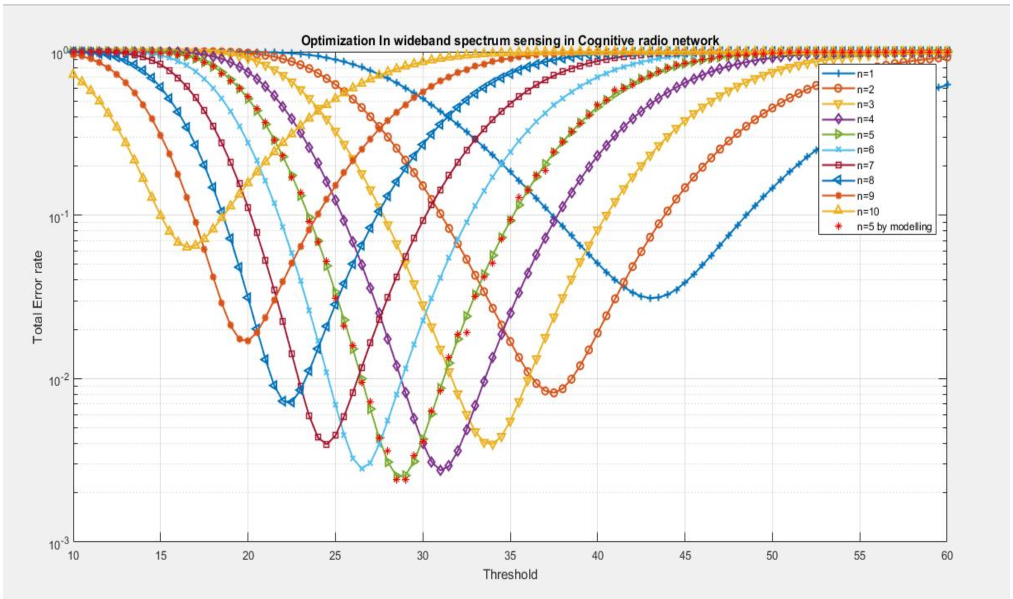

Figure 9: plot of total error rate vs threshold

5.4 ROC Curve for Probability of Detection vs Probability of False Alarm

The probability of False Alarm is the probability of falsely detecting the Primary Signal when the primary user is actually silent in the scanned frequency band.

Probability of Detection is the Probability that the Primary User present in the specified band is correctly detected and the band is shown to be occupied.

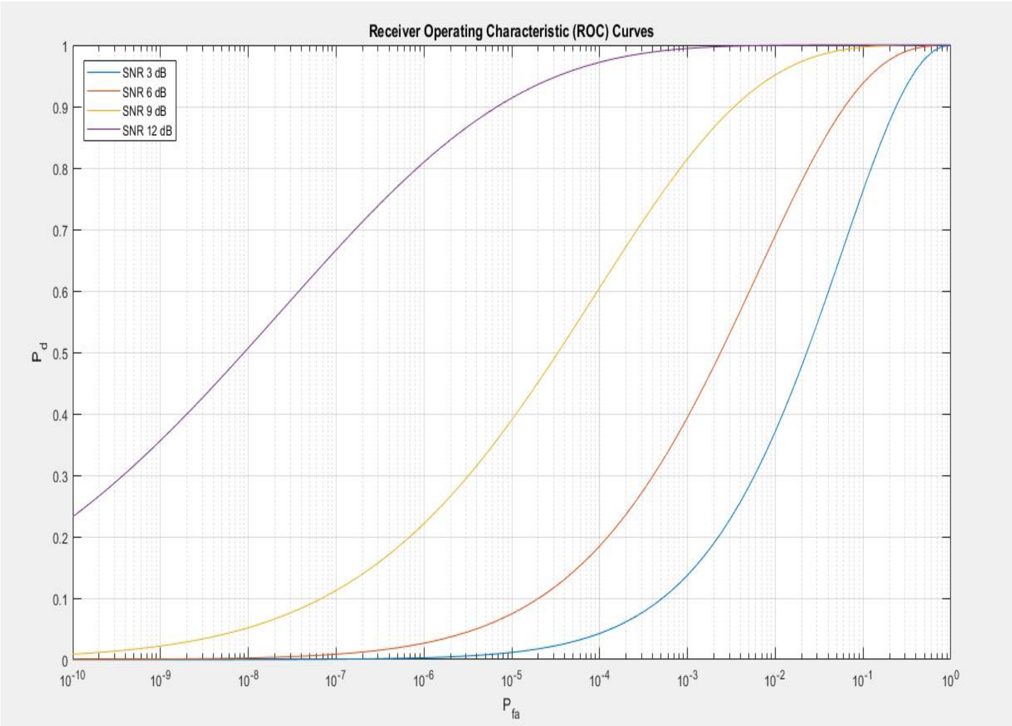

Figure 10 : ROC Curve for Probability of detection vs Probability of false alarm for a fixed SNR

The graph shows the Probability of detection vs Probability of false alarm for fixed SNR values.

Signal-to-noise ratio (abbreviated SNR or *S/N*) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise.

SNR is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.

SNR=Power of signal/Power of noise

From the graph we can confer the following table :

SI no.	SNR	Probability of detection	Probability of False Alarm	False Alarm Rate	Probability of missed detection
1	3 dB	0.75	10^{-1}	1 false Alarm in every 10 samples.	0.25
2	6 dB	0.70	10^{-2}	1 false Alarm in 100 samples.	0.30
3	9 dB	0.23	10^{-6}	1 false alarm every 1000000 samples.	0.77
4	12 dB	0.24	10^{-10}	1 false alarm every 10000000000 samples.	0.76

Table 2 :Values obtained from the probability of detection vs probability of false alarm curve

So the false alarm and the probability of detection can be correlated and it is shown in the table.

5.5 ROC CURVE FOR SNR vs PROBABILITY OF DETECTION

Here we will plot Probability of Detection vs SNR for a constant false alarm rate. Lets assume Probability of False alarm rate= 0.20, and study the graph obtained as below.

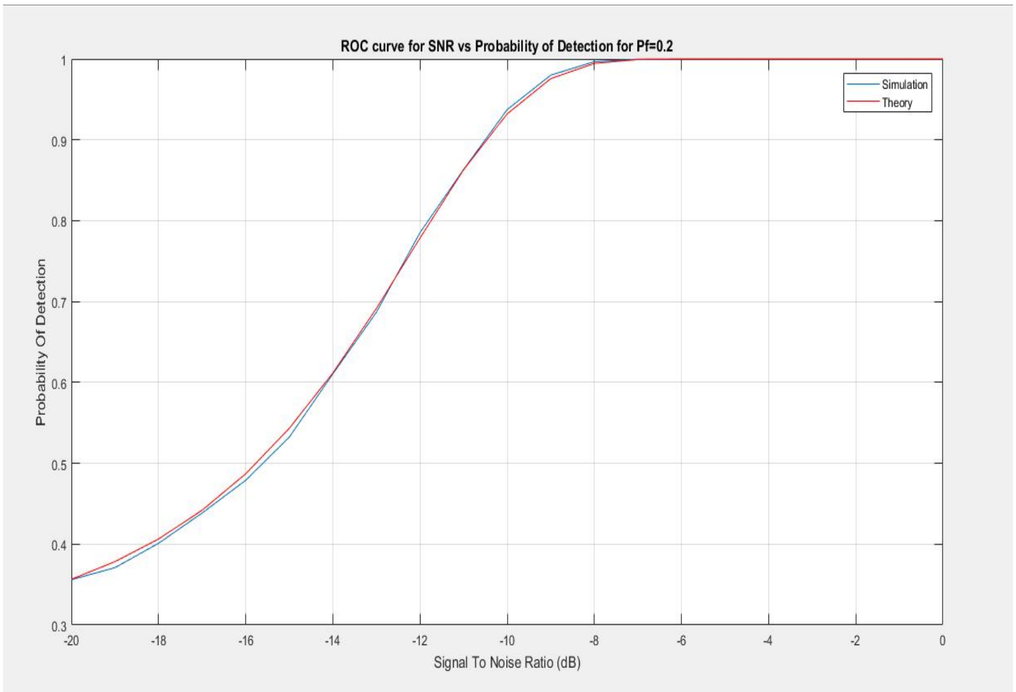

Figure 11: Curve of probability of detection vs SNR for constant Probability of false alarm rate

Here we are calculating the theoretical value of Probability of Detection and then comparing it with the simulated value.

Pd_the = Q(((threshold - (snr + 1)).* $(L)^{0.5}$)./$((2)^{0.5}$ * (snr + 1)));
% probability detection theoretical value.
Where snr= signal to noise ratio.
Thresh=threshold value that is fixed based on the input energy stream

Analysis of the graph :

Probability of false alarm= 0.20

SI no.	SNR in Decibels	Probability of Detection Pd	Probability of Missed Detection
1	-4	1	0
2	-8	0.99	0.01

3	-12	0.78	0.22
4	-16	0.48	0.52

Table 3 :Values obtained from the probability of detection vs SNR curve

Using these graphs, the presence or the absence of Primary users can be detected.

CHAPTER 6
SOFTWARE DESCRIPTION

6.1 SOFTWARE DESCRIPTION

6.1.1 OVERVIEW OF MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

Typical uses include

• Math and computation

• Algorithm development

• Data acquisition

• Modeling, simulation, and prototyping

• Data analysis, exploration, and visualization

• Scientific and engineering graphics

• Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or FORTRAN. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.The MATLAB System

The MATLAB system consists of these main parts:

6.1.2 DESKTOP TOOLS AND DEVELOPMENT ENVIRONMENT

This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, a code analyzer and other reports, and browsers for viewing help, the workspace, files, and the search path.

6.1.3 MATLAB MATHEMATICAL FUNCTION LIBRARY

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

6.1.4 MATLAB LANGUAGE

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both “programming in the small” to rapidly create quick and dirty throw-away programs, and “programming in the large” to create large and complex application programs.

6.1.5 GRAPHICS

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on THE MATLAB applications.

6.1 .6 MATLAB EXTERNAL INTERFACES

This is a library that allows you to write C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

CHAPTER 7

CONCLUSION

So using the subnyquist spectrum sensing we can detect the presence of primary users in the narrowbands of the wideband signal. The energies of consecutive narrowbands are compared and the power spectral density is compared to detect the presence of primary users.The probability of detection and the probability of false alarm curves are shown to detect the presence of a primary user.The threshold of detection is fixed based on the energies of the narrowbands in the spectrum. The decision threshold and the probability of detection under the Neyman Pearson criterion are provided, which show that the decision threshold is unrelated to the noise power.Using all these factors the presence of a primary user in the spectrum can be detected.

CHAPTER 8

FUTURE ENHANCEMENT

The work done in this project can be enhanced in numerous ways in the future for even better results. This can be achieved in various ways:

- Detecting the presence of Primary Users
- Accomodating Secondary licensed Users in the bands unoccupied by Primary Users
- Improving Spectral efficiency by accommodating more number of wireless users.

REFERENCES

- H. Sun, W. Y. Chiu, and A. Nallanathan, “Adaptive Compressive Spectrum Sensing for Wideband Cognitive Radios,” IEEE Communications Letters, vol. 16, no. 11, pp. 1812–1815, Nov. 2012.

- Z. Tian and G. B. Giannakis, “Compressed Sensing for Wideband Cognitive Radios,” in 2007 IEEE International Conference on Acoustics, Speech and Signal Processing – ICASSP ’07, vol. 4, April 2007, pp. IV– 1357–IV–1360.

- Y. Zeng and Y. C. Liang, “Spectrum-sensing algorithms for cognitive radio based on statistical covariances,” IEEE Transactions on Vehicular Technology, vol. 58, no. 4, pp. 1804–1815, May 2009

- H. Sun, A. Nallanathan, C. X. Wang, and Y. Chen, “Wideband Spectrum Sensing for Cognitive Radio Networks: A Survey,” IEEE Wireless Communications, vol. 20, no. 2, pp. 74–81, April 2013.