SPECTRUM SENSING METHODS IN COGNITIVE RADIO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Electronics and Communication Engineering

Under the aegis of

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2011

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitles "Spectrum Sensing Methods in Cognitive Radio" submitted by Siddharth Jain (Roll no: 107EC024) and Ravi Baid Jain (Roll no: 107EC026) in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Communication at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in thesis has not been submitted to any other university/ institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

We owe the deepest gratitude to Prof. SARAT KUMAR PATRA, (HOD Electronics Dept.), our supervisor on this project, for his guidance and constant support without which this project would not have materialized. He always helped out with our problems and gave us time in spite of his busy schedules, more importantly he motivated us to put in relentless efforts and kept on pushing us for more.

We also appreciate Prof. K.K.Mahapatra, Prof. S.K.Behera, Prof. Poonam Singh , Prof. D.P.Acharya Prof. S.K. Das, ,Prof. N. Murthy,Prof. S. Ari and Prof. A. Sahoo and other staff members for the invaluable feedback and comments that helped us improve our work.

We are indebted to Prof. S. Meher who encouraged us to take a project in wireless field as both of us had keen interest in it.

We are also thankful to Research Scholars and M. Tech. students for their co-operation in usage of laboratories and to all our friends who have directly or indirectly helped us with the thesis and project.

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ABSTRACT

Cognitive Radio offers a solution by utilizing the spectrum holes that represent the potential opportunities for non-interfering use of spectrum which requires three main tasks- Spectrum Sensing, Spectrum Analysis and Spectrum Allocation. Spectrum sensing involves obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency, and code and determining what type of signals are occupying the spectrum. In this project, OFDM based Cognitive Radio and Spectrum Sensing methods namely Energy Detection Based Spectrum Sensing with Wavelet packet transform and Cyclostationary Spectrum Sensing are discussed.

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LIST OF ABBREVIATIONS

BPSK – Binary Phase Shift Keying

CP – Cyclic Prefix

CR – Cognitive Radio

CSS – Cyclostationary Spectrum Sensing

DARPA- Defense Advance Research Products Agency

DFT- Discrete Fourier Transform

FCC – Federal Communications Commission

FFT- Fast Fourier Transform

ICI – Inter Channel Interference

LAN- Local Area Network

MBMS - Multimedia Broadcast and Multicast Services

OFDM – Orthogonal Frequency Division Multiplexing

PCS - Personal Communication Services

P_D - Probability of Detection

PU - Primary Users

QPSK – Quadrature Phase Shift Keying

RKRL – Radio Knowledge Representation Language

STFT - Short Time Fourier Transform

SU - Secondary Users

WLAN - Wireless Local Area Network

WMAN - Wireless Metropolitan Area Network

WPT - Wavelet Packet Transform

WRAN - Wireless Rural Area Network

INTRODUCTION

According to survey of Federal Communications Commision (FCC) in 2002, it has been found that spectrum access is more significant problem than physical scarcity of spectrum [5].With many technological advances in the field of wireless communication and 3G, 3.5G, 3.75G and 4G technology already being employed Multimedia Broadcast and Multicast Services (MBMS) demand has tremendously increased and with the standardization of MBMS it has gained significant interest in the market. Multimedia content requires more bandwidth, storage capacity and few applications pose tight delay constraints, so the need to optimize the utilization of spectrum is felt all the more.

Cognitive radio arises to be a tempting solution to spectral crowding problem by introducing the opportunistic usage of frequency bands that are not heavily occupied by licensed users since they cannot be utilized by users other than the license owners at the moment. Orthogonal Frequency Division Multiplexing (OFDM) is one of the most widely used technologies in current wireless communication systems which has the potential of fulfilling the requirements of cognitive radios inherently or with minor changes. With it interoperability among the different protocols becomes easier which is one of the important requirements in Cognitive radio.

Chapter 1

INTRODUCTION TO COGNITIVE RADIO

1.1 COGNITIVE RADIO

Cognitive Radio (CR) is a system/model for wireless communication. It is built on software defined radio which is an emerging technology providing a platform for flexible radio systems, multiservice, multi-standard, multiband, reconfigurable and reprogrammable by software for Personal Communication Services (PCS). It uses the methodology of sensing and learning from the environment and adapting to statistical variations in real time. The network or wireless node changes its transmission or reception parameters to communicate efficiently anywhere and anytime avoiding interference with licensed or unlicensed users for efficient utilization of the radio spectrum.

Cognitive modules in the transmitter and receiver must work in a harmonious manner which is achieved via a feedback channel connecting them. Receiver is enabled to convey information on the performance of the forward link to the transmitter. Thus CR by necessity is an example of a feedback communication system [1].

The concept was first originated by Defense Advance Research Products Agency (DARPA) scientist, Dr. Joseph Mitola and the result of that concept is IEEE 802.22 , which is a standard aimed at using cognitive radio for Wireless Regional Area Network (WRAN) using white spaces in the TV frequency spectrum while assuring that no harmful interference is caused to the incumbent operation, i.e., digital TV and analog TV broadcasting, and low power licensed devices. IEEE P802.22.1 is a standard being developed to enhance harmful interference protection for low power licensed devices operating in TV Broadcast Bands in the 700 MHz band[3]. IEEE P802.22.2 is a recommended practice for the installation and deployment of IEEE 802.22 System. IEEE 802.22 WG is a working group of IEEE 802 LAN/MAN standards committee which is chartered to write the 802.22 standard. The two 802.22 task groups (TG1 and TG2) are writing 802.22.1 and 802.22.2 respectively [4].

1.1a Software radio

Software Radio is an emerging technology that provides platform for flexible radio systems, multiservice, multistandard, multiband, reconfigurable and reprogrammable by software for PCS. Cognitive radio extends the software radio with radio-domain model-based reasoning about such radio etiquettes enhancing the flexibility of personal services through a Radio Knowledge Representation Language (RKRL).

1.1b Radio Etiquettes

Radio Etiquettes are the set of RF bands, air interfaces, protocols, and spatial and temporal patterns that moderate the use of the radio spectrum.

1.1c Radio Knowledge Representation Language

RKRL represents knowledge of radio etiquette, devices, software modules, propagation, networks, user needs, and application scenarios to support automated reasoning about the needs of the user. It empowers software radios to conduct negotiations among peers about the use of radio spectrum across fluents of space, time, and user context and actively manipulate the protocol stack to adapt known etiquettes to better satisfy the user's needs even if the user doesn't know how to obtain them[7].

1.2 COGNITIVE CYCLE

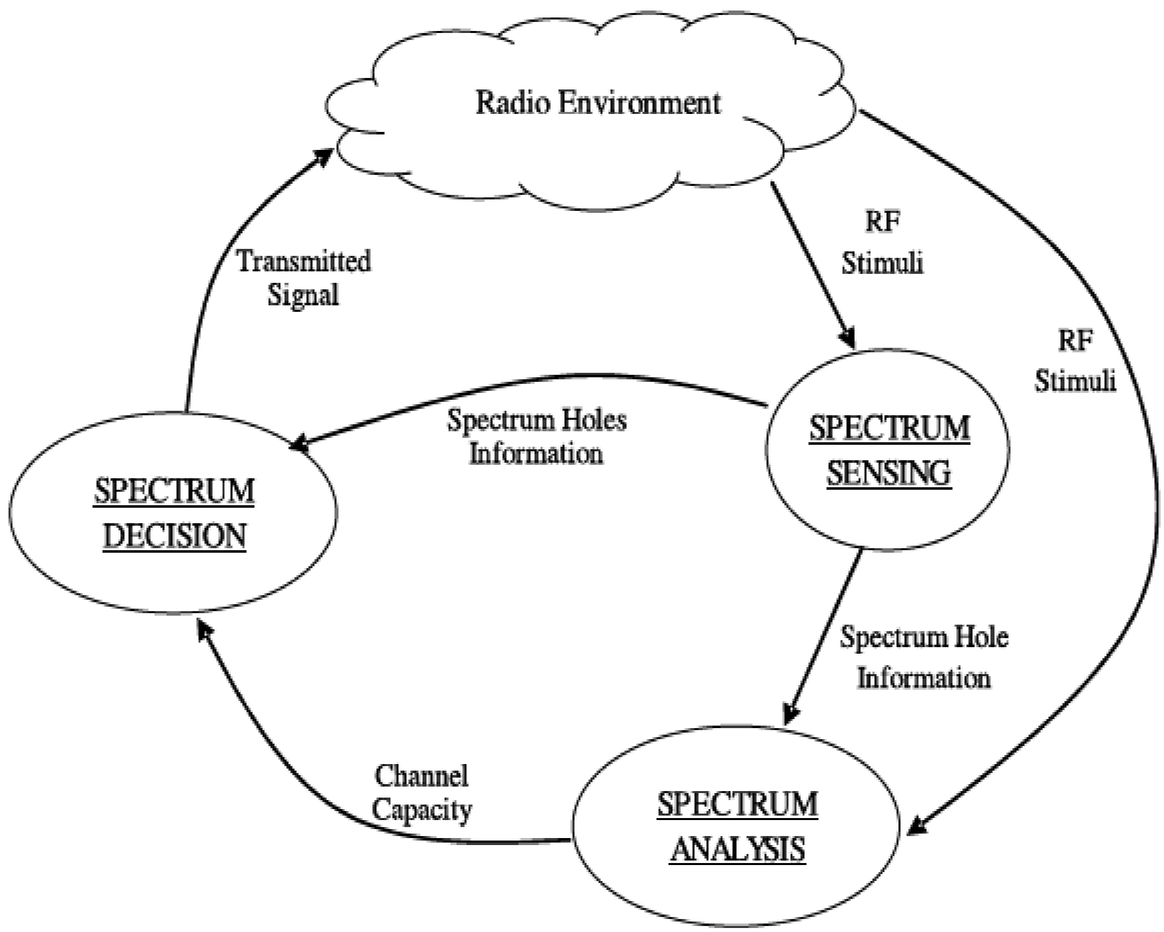

Figure 1 - Cognitive cycle

A basic cognitive cycle comprises of following three basic tasks:

- Spectrum Sensing
- Spectrum Analysis
- Spectrum Decision Making

1.3 COGNITIVE RADIO'S CAPABILITIES

1.3a Spectrum Sensing

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase.

1.3b Spectrum Analysis

Spectrum Analysis is based on spectrum sensing which is analyzing the situation of several factors in the external and internal radio environment (such as radio frequency spectrum use by neighboring devices, user behavior and network state) and finding the optimal communication protocol and changing frequency or channel accordingly. It is also known as channel estimation.

1.3c Spectrum Decision Making

Spectrum Decision Making calls for reconfiguration for the channel and protocol required for constantly adapting to mobile changing environments and adjustment of output power or even alteration of transmission parameters (such as modulation formats (e.g. low to high order QAM), variable symbol rates, different channel coding schemes) and characteristics by the Cognitive radio devices. CR should be able to use multiple antennas for interference nulling, capacity increase or range extension.

1.4 COGNITIVE RADIO’S KEY BENEFITS

Cognitive Radio offers optimal diversity (in frequency, power, modulation, coding, space, time, polarization and so on) which leads to:

- **Spectrum Efficiency**- This will allow future demand for spectrum to be met and is the basic purpose of implementing CR.
- **Higher bandwidth services-** Demand of MBMS is constantly on the rise which will be facilitated by the implementation of CR.
- **Graceful Degradation of Services -** When conditions are not ideal, a graceful degradation of service is provided, as opposed to the less desirable complete and sudden loss of service. This feature of CR is very important in providing services to the users especially when they are mobile and the base stations in contact are constantly changing.
- **Improved Quality of Service (QoS)** (latency, data rate, cost etc) - Suitability, availability and reliability of wireless services will improve from the user’s perspective.
- **Commercial Exploitation**- CR promotes spectrum liberalization (makes it much easier to trade spectrum between users). Indeed, a business case may exist for becoming a spectrum broker, whereby a third party manages the trade between supplier and demander and receives a commission.
- **Benefits to the Service Provider**- More customers in the market and/or increased information transfer rates to existing customers. More players can come in the market.
- **Future-proofed product**- A CR is able to change to services, protocols, modulation, spectrum etc. without the need for a user and/or manufacturer to upgrade to a new device.

- **Common hardware platform**- Manufacturers will gain from economies of scale because they no longer need to build numerous hardware variants, instead using a single common platform to run a wide range of software. This also assists in rapid service deployment.
- **Flexible regulation**-By using a form of policy database, regulation could be changed relatively quickly as and when required, easing the burden on regulators.

- **Emergency service communications**- Joint operations during major incidents would benefit greatly as police, fire, ambulance and coastguard could be linked together in one radio with each radio user sensing the spectrum being used by the other parties and reconfiguring itself.

- **Benefits to the Licensee**- CR can pave the way for spectrum trading, where licensees would be allowed to lease a portion of their spectrum rights to third parties on a temporal, spatial or other appropriate basis to recoup some of the expense of its 24hr-a-day license and even make money.

Chapter 2

OFDM BASED COGNITIVE RADIO

2.1 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

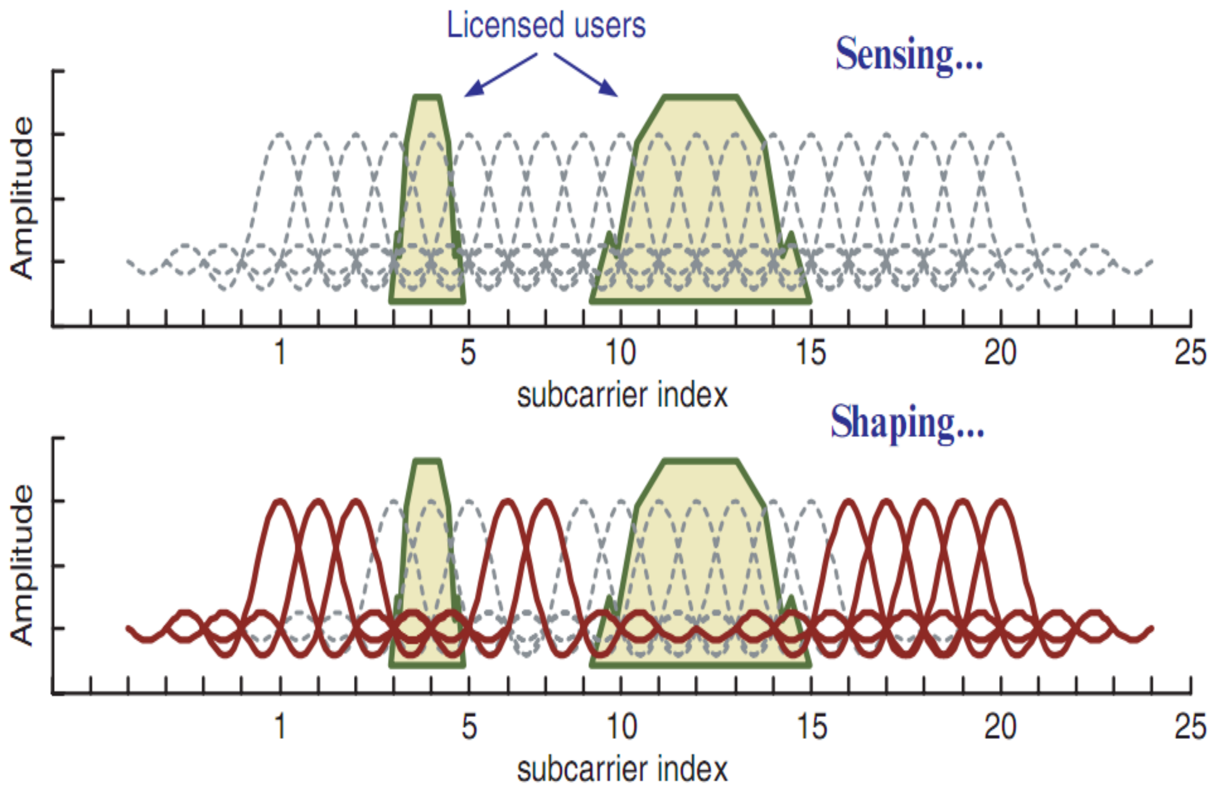

Figure 2 - Spectrum sensing and shaping using OFDM [2]

Orthogonal Frequency Division Multiplexing (OFDM) signal can be considered as group of narrow band signals, and by increasing the number of subcarriers, the bandwidth of each subcarrier becomes narrower.

By choosing the subcarrier spacing to be less than the coherence bandwidth of the channel, each subcarrier is going to be affected by a flat channel and thus no channel equalization is needed.

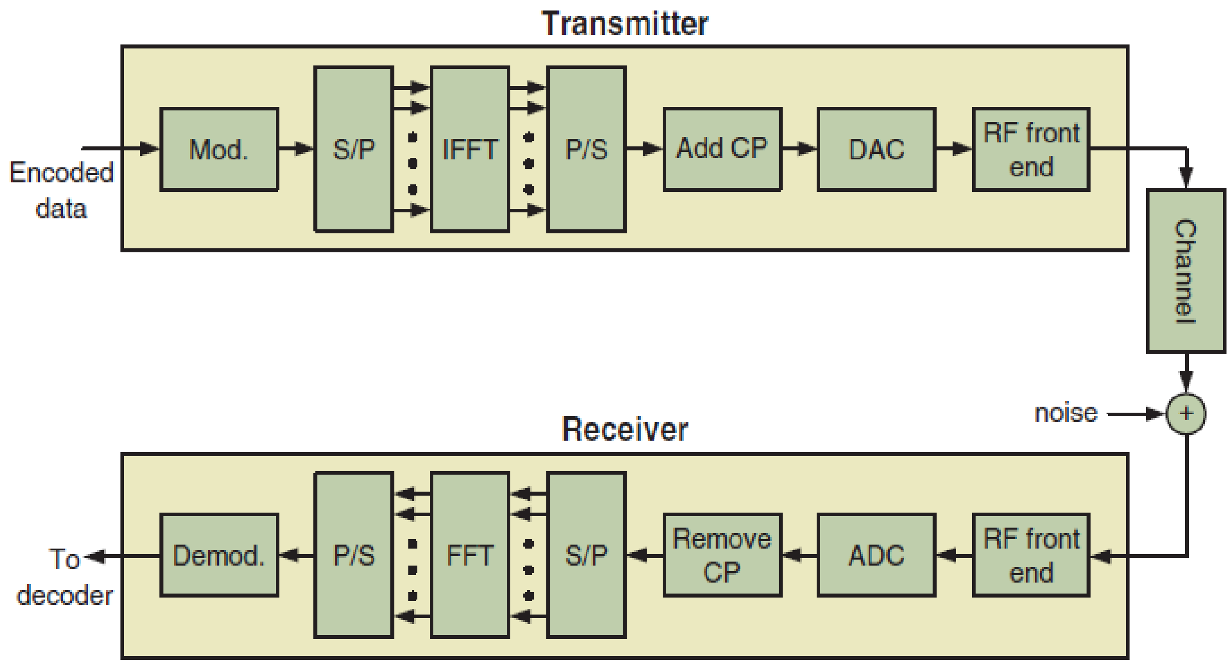

Figure 3 - Basic block diagram of OFDM transceiver [2]

To avoid ISI, symbols duration is extended by adding a guard band to the beginning of each symbol in what is known as Cyclic Prefix (CP).If we define the delay spread (or multipath spread) of the channel as the delay between the first and last received paths over the channel, the CP should be longer than that delay. However, to avoid fast fading effect, OFDM symbol time is chosen to be shorter than the coherence time of the channel.

In the frequency domain, mobility results in a frequency spread of the signal which depends on the operating frequency and the relative speed between the transmitter and receiver, also known as Doppler spread. Doppler spread of OFDM signals results in Inter-Carrier Interference (ICI) which can be reduced by increasing the subcarrier spacing.

2.2 FLEXIBILITY OFFERED BY OFDM

The transmission parameters that can be changed based on the spectrum awareness include bandwidth, FFT size, filters, windows, modulation, transmit power, and active subcarriers used for transmission.

The parameters that can be adapted depending on the characteristics of the environment in order to optimize the transmission include cyclic prefix size, coding rate/type, modulation type, interleaving method, pilot patterns, preambles/midambles and duplexing method.

While employing CR, Secondary Users (SUs) should not interfere with other licensed users using the spectrum; so to guarantee an interference-free communication between rental users, the spectrum sensing information between multiple cognitive radio devices needs to be shared to decrease or even eliminate the probability of interference with licensed users.

The processing time too plays an important role as spectrum sensing is done frequently, so the overhead of sharing such information will increase, thus reducing the spectrum efficiency of the whole system and increasing the system complexity but in OFDM systems, conversion from time domain to frequency domain is achieved inherently by using Discrete Fourier Transform (DFT). Hence, all the points in the time–frequency grid can be scanned without any extra hardware and computation because of the hardware reuse of Fast Fourier Transform (FFT) [2].

2.2a Issues of concern in OFDM

Mutual interference should be carefully considered when designing cognitive radio systems. The side lobes of modulated OFDM subcarriers are known to be large. As a result, there will there will be power leakage from used subcarriers to nulled subcarriers which causes interference to the licensed users. One method is to make the *sinc* decay faster by windowing the time domain OFDM sample.

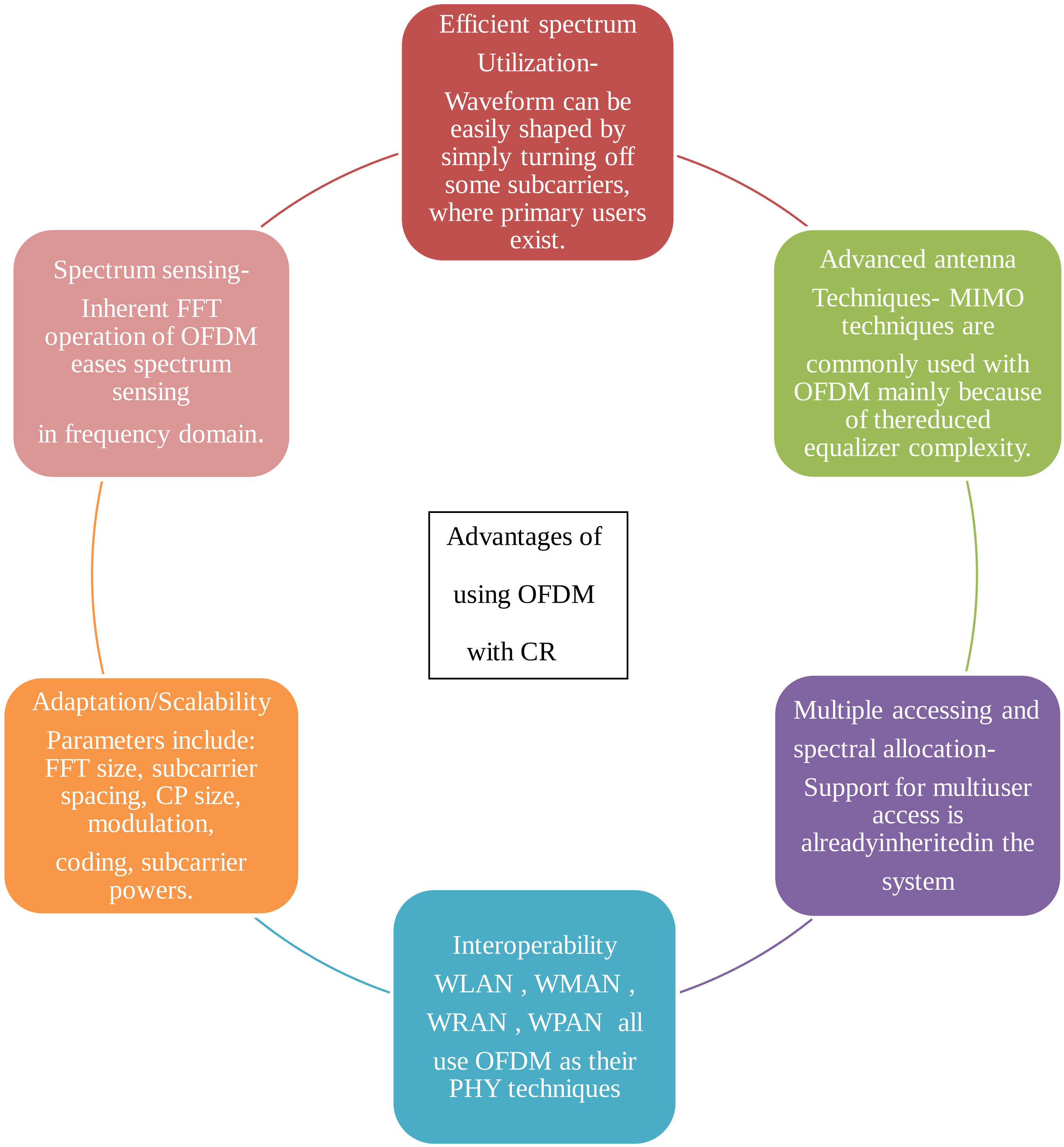

Figure 4 – Advantages of using OFDM with CR

[12]

Chapter 3

SPECTRUM SENSING

3.1 SPECTRUM SENSING

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions. It is done across Frequency, Time, Geographical Space, Code and Phase.

3.1a Spectrum Sensing Methods

A number of different methods are proposed for identifying the presence of signal transmission all of which are in early development stage. They are:

- Energy – Detection Based
- Waveform Based
- Cyclostationary – Based
- Radio Identification Based
- Matched filtering Based

We will be dealing with Energy detection Wavelet Packet based spectrum sensing.

3.2 ENERGY DETECTION BASED SPECTRUM SENSING

Energy Detection is the most common way of spectrum sensing because of its low computational and implementation complexities. It is a more generic method as the receivers do not need any knowledge on the primary user's signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. The important challenge with the energy detector based sensing is the selection of the threshold for detecting primary users. The other challenges include inability to differentiate interference from primary users and noise and poor performance under low signal-to-noise ratio values.

P_D (probability of detection) and P_F (probability of false alarm) are the important factors for energy based detection which gives the information of the availability of the spectrum.

3.3 WAVELET TRANSFORM

The Wavelet Transform has recently gained a lot of popularity in the field of signal processing due to its capability of providing both time and frequency information simultaneously, hence giving a time-frequency representation of the signal.

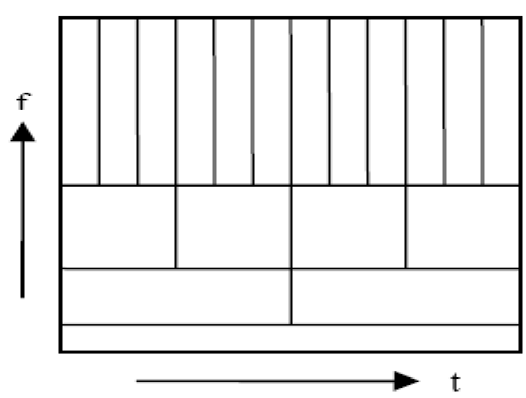

Figure 5 – Resolution of time and frequency in Wavelet Transform

The traditional Fourier Transform can only provide spectral information about a signal and only works for stationary signals whereas in many real world applications, the signals are non-stationary and needs to be processed in real time. The problem with Short Time Fourier Transform (STFT) goes back to the Heisenberg uncertainty principle which states that it is impossible for one to obtain which frequencies exist at which time instance but, one can obtain the frequency bands existing in a time interval. Also the window used in STFT is of constant length whereas with Wavelet transform we can have multi resolution analysis i.e. we can

- Analyze the signal at different frequencies with different resolutions.
- Have good time resolution and poor frequency resolution at high frequencies.
- Have good frequency resolution and poor time resolution at low frequencies .

Also it is more suitable for short duration of higher frequency and longer duration of lower frequency components.

3.4 WAVELET PACKET TRANSFORM

For application of interest noise is primarily of high frequency and the signal of interest is primarily of low frequency. The wavelet transform decomposes the signal into approximation (low frequency) and details (high frequency) coefficients, the detail coefficients containing much noise. The simple method to denoise the signal is to simply reduce the size of the detail coefficients before using them to reconstruct the signal. This approach is called thresholding. The detail coefficients cannot be made zero since they contain some important features of the original signal. The two different approaches which are usually applied to denoise are hard thresholding and soft thresholding.

Wavelet packet transform is a generalization of wavelet transform which keep splitting both low pass and high pass sub-bands at all scales in the filter bank approximation and implementation. Hence it is suitable to finely identify the information in both high and low frequency bands and thus is an ideal processing tool for non-stationary time-variable signal.

The following figure is the wavelet packet decomposition tree.

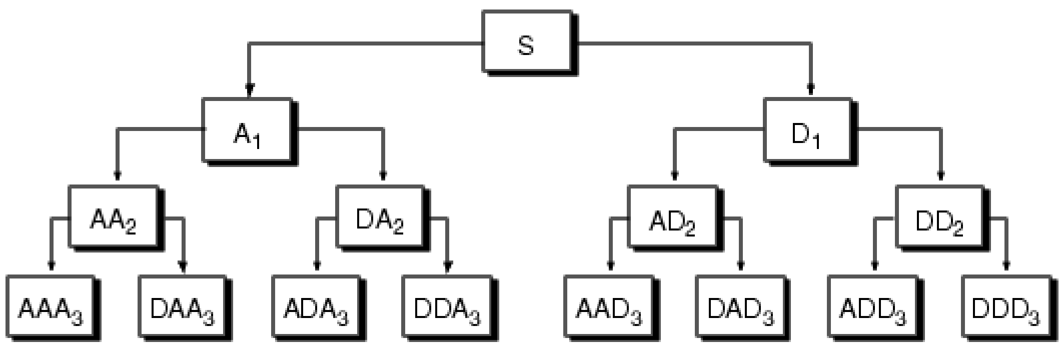

Figure 6 – Wavelet packet decomposition tree

Wavelet packet analysis allows the signal S to be represented as A1 + AAD3 + DAD3 + DD2. This is an example of a representation that is not possible with ordinary wavelet analysis but made feasible only with Wavelet Packet Transform.

3.5 ENERGY DETECTION MODEL BASED ON WAVELET PACKET TRANSFORM

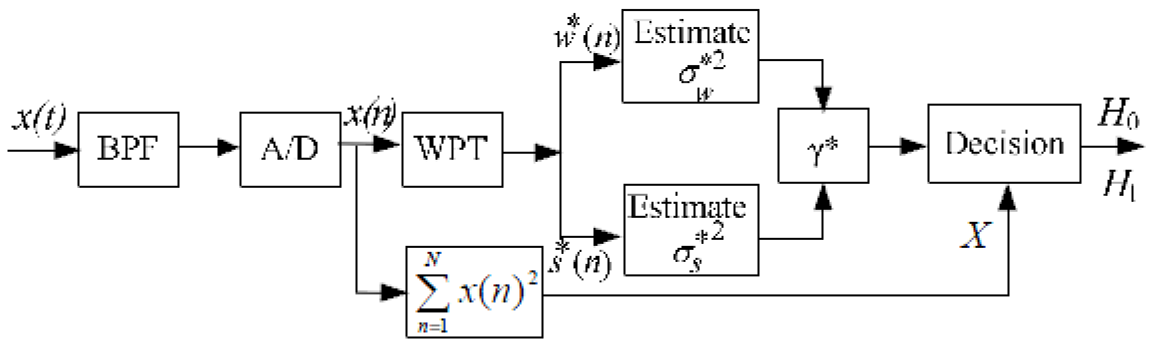

Figure 7 - Block diagram of Energy Detection Model based on WPT [8]

The block diagram is similar to the simplest energy based detector but most importantly a Wavelet Packet Transform (WPT) block has been introduced which estimates the current noise and signal power, which is very important for settling threshold. The analog signal x(t) after being converted into digital signal x(n) is decomposed for a certain level related to the resolution required and then is reconstructed by wavelet packet decomposition coefficients. And hence the noise power and reconstructed signal power is estimated.

3.6 CYCLOSTATIONARY SPECTRUM SENSING

When a transmitted signal is modulated with a sinusoidal carrier, cyclic prefixes (as in OFDM), code or hopping sequences (as in CDMA); cyclostationarity is induced i.e. mean, autocorrelation show periodic behavior. This feature is exploited in a Cyclostationary Feature Detector that measures a signal property called Spectral Correlation Function..

Figure 8 - Cyclostationary Feature Detector

3.7 ADVANTAGES & DISADVANTAGES OF CYCLOSTATIONARY SPECTRUM SENSING

Cyclostationary Spectrum Sensing performs better than Energy detection because of its noise rejection ability. This occurs because noise is totally random and does not exhibit any periodic behavior. When we have no prior knowledge about primary user's waveform which is the scenario in real life, then best technique is cyclostationary feature detection.[11].

The disadvantage with cyclostationary spectrum sensing is its high complexity which results in high cost.

Chapter 4

RESULTS
&
INFERENCES

4.1 SIMULATION OF P_D VS SNR USING WPT

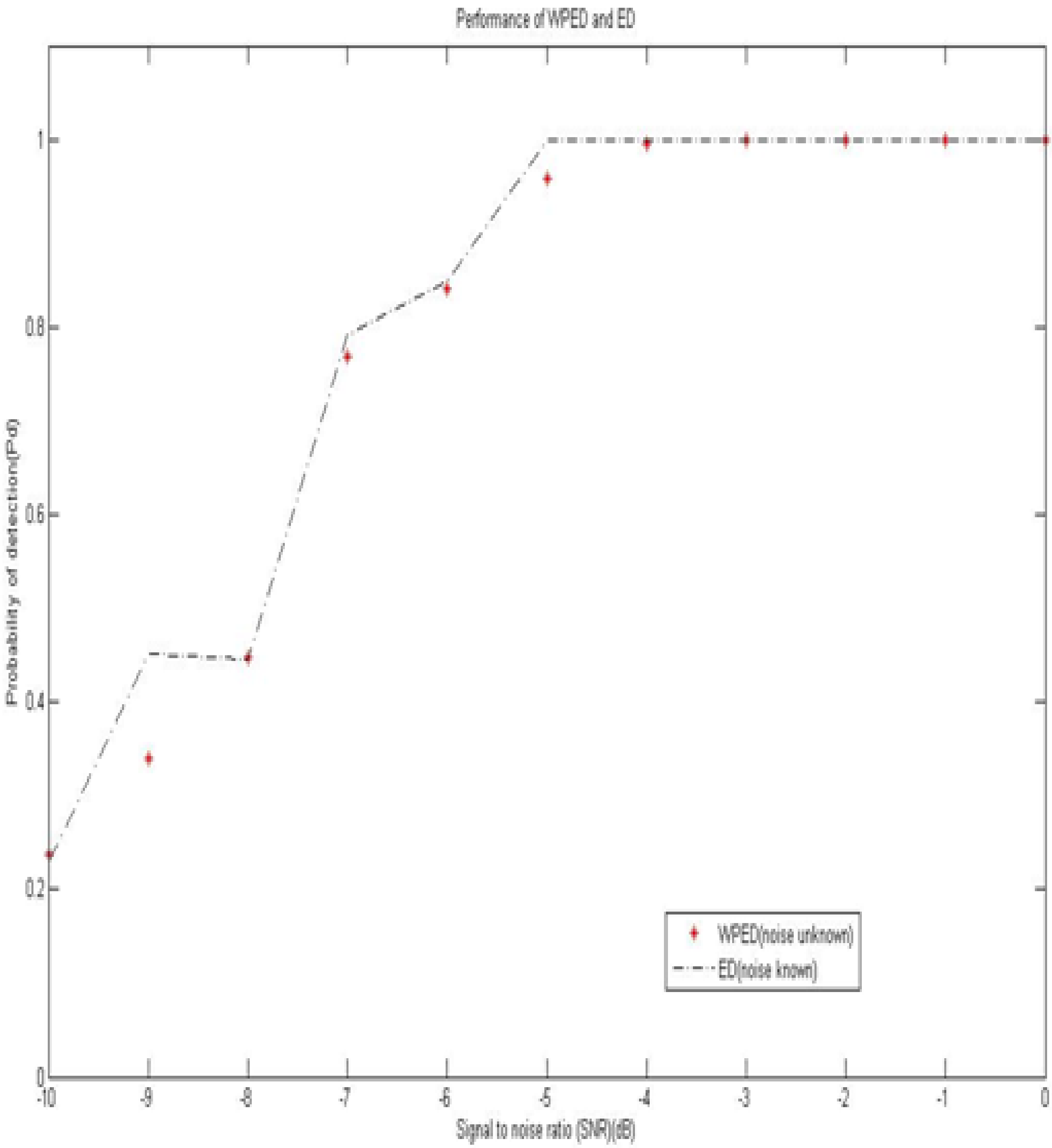

Figure 9 - Simulation of Probability of detection vs SNR using WPT

4.1a Algorithm

Step1 – A random signal is generated.

Step2 – Additive White Gaussian noise is added.

Step3 –The signal is added with AWGN and the new signal is obtained whose WPT is found out.

Step4 – The level of threshold is decided and variance is calculated.

Step5 - Probability of detection is calculated at various SNR using WPT.

4.1b Result and Inference

The estimated noise power, signal power and decision threshold by Wavelet Packet Transform (WPT) method were in match with the values and graph plotted with the traditional Energy Detection method when the noise was known. Hence WPT is quite a robust method for CR applications when the noise is unknown.

4.2 SIMULATION OF PROBABILITY OF DETECTION VS SNR USING WPT UNDER DIFFERENT SAMPLE NUMBERS

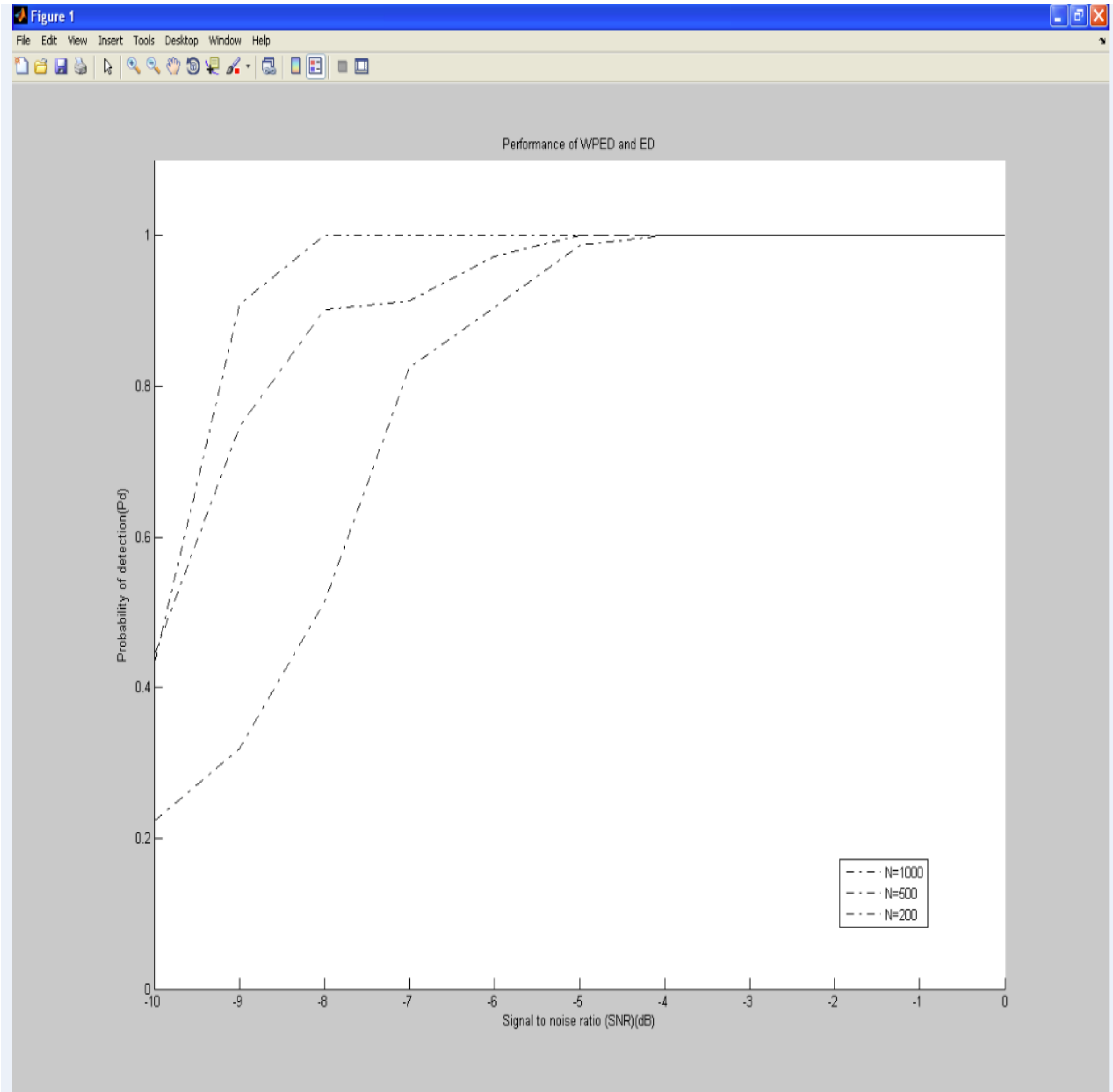

Figure 10 - Simulation of P_D vs SNR using WPT under different sample numbers

4.2a Result & Inference

- As the sample number increases the performance of the WPED method rises evidently.
- When the sample number N is large enough the probability of detection is close to 1.
- Therefore spectrum sensing done with more number of samples gives better results.

4.3 SIMULATION OF PROBABILITY OF DETECTION VS SNR USING WPT UNDER DIFFERENT WAVELETS

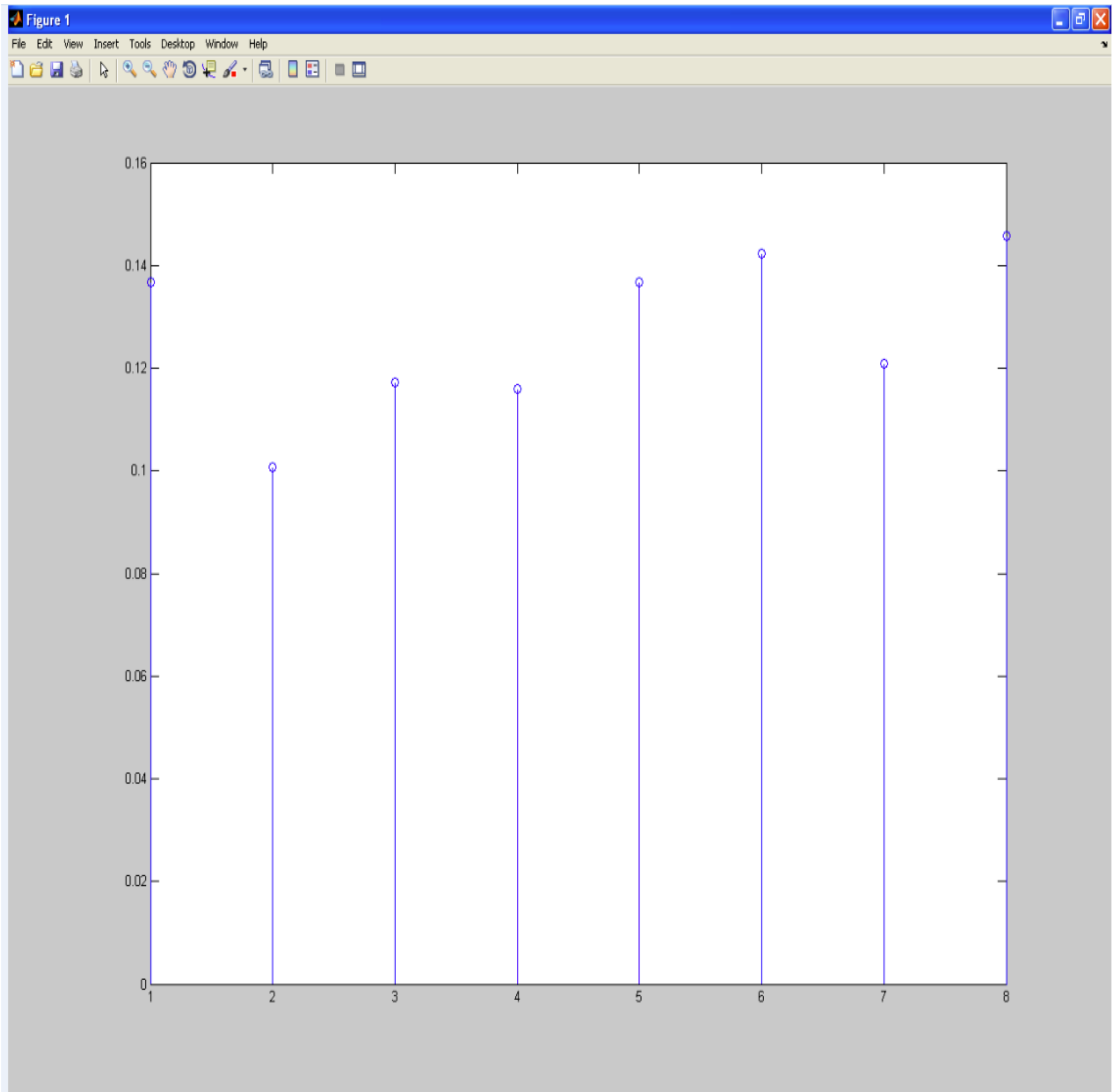

Figure 11 - Simulation of P_D vs SNR using WPT under different wavelets

4.3a Result & Inference

We infer that among the different wavelets used for Energy Detection based Spectrum Sensing, db2 wavelet gives the minimum error when used for the decomposition and reconstruction of the signal. Hence the wavelet db2 is most suitable for performing energy detection based spectrum sensing when done with the help of WPT.

4.4 SIMULATION OF CYCLOSTATIONARY SPECTRUM SENSING WITH QPSK MODULATION

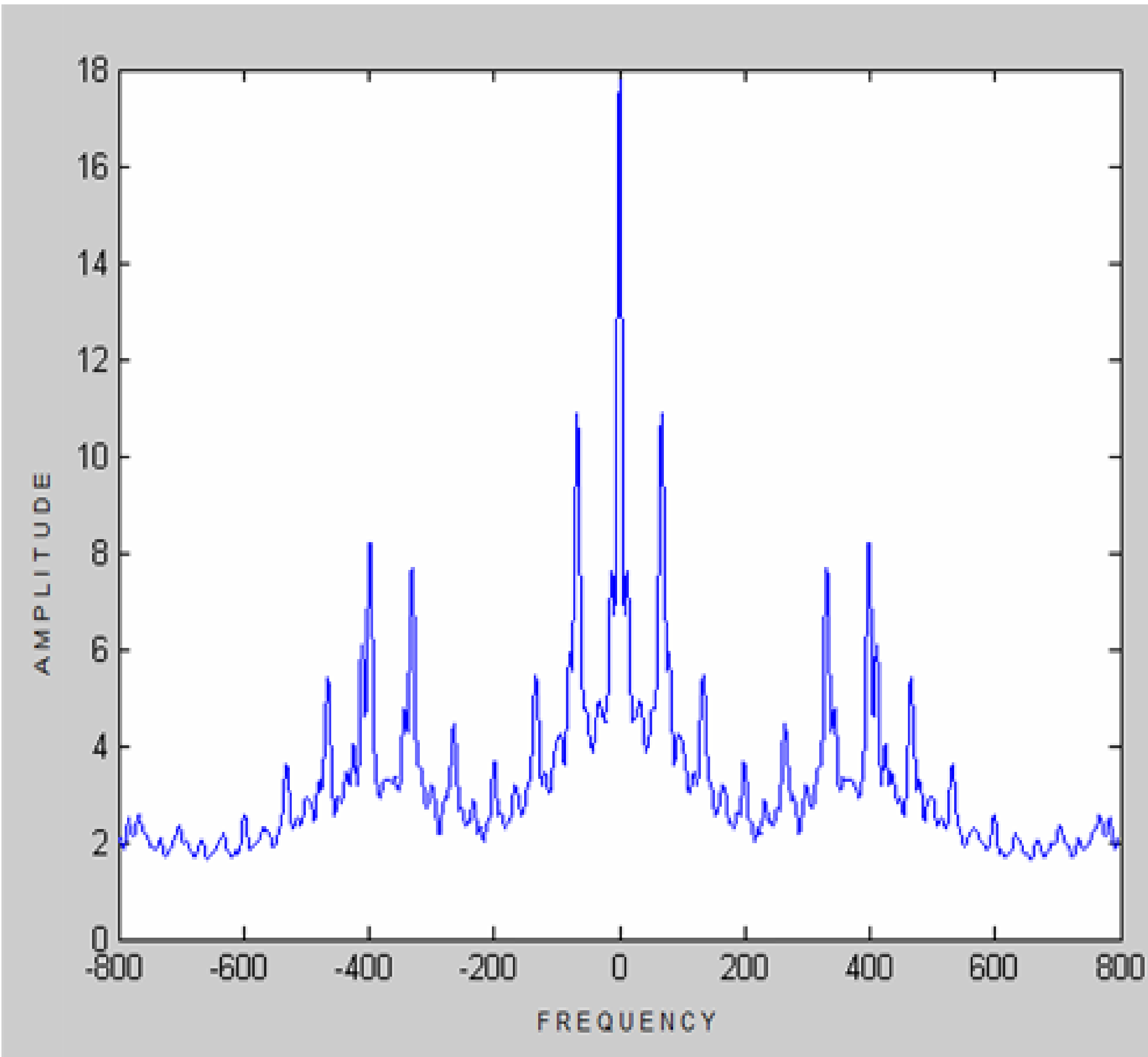

Figure 12 - Simulation of cyclostationary spectrum sensing with QPSK modulation

4.4a Result & Inference

When the transmitted signal used is QPSK modulated and the carrier frequency is 200 Hz and cyclostationary spectrum sensing is performed, we get two peaks at 400Hz frequency. The two peaks signify that the modulation scheme used by the primary user is QPSK and the reason for getting peaks at double the carrier frequency is autocorrelation of the received signal.

4.5 SIMULATION OF CYCLOSTATIONARY SPECTRUM SENSING WITH BPSK MODULATION

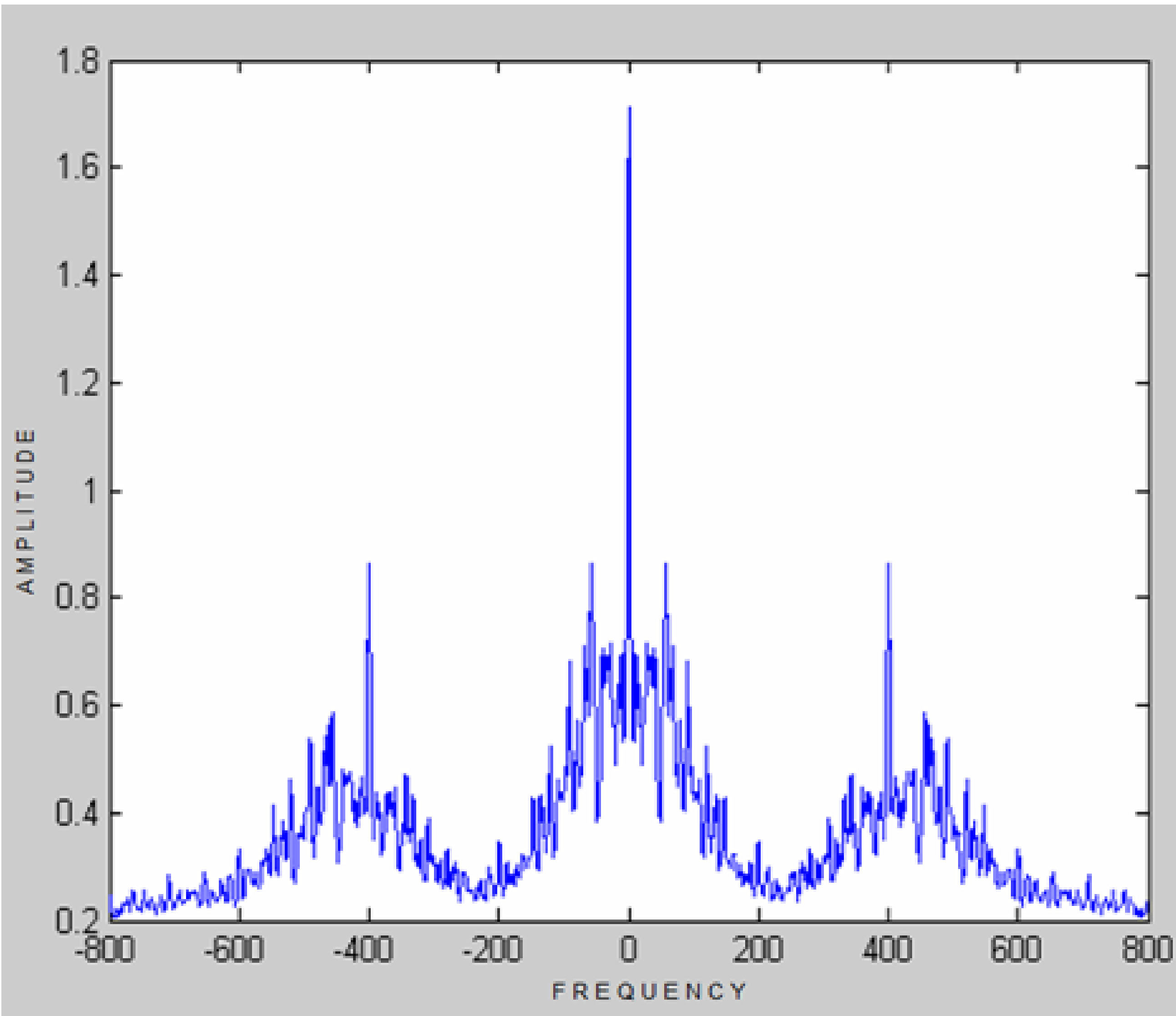

Figure 13 - Simulation of cyclostationary spectrum sensing with BPSK modulation

4.4a Result & Inference

When the transmitted signal used is BPSK modulated and the carrier frequency is 200 Hz and cyclostationary spectrum sensing is performed, we get a single peak at 400Hz frequency which signifies that the modulation scheme used by the primary user is BPSK and the reason for getting a peak at double the carrier frequency is autocorrelation of the received signal.

Chapter 5

CONCLUSIONS

5.1 Conclusion

Energy Detection spectrum sensing using Wavelet Packet Transform (WPED) method outperforms the traditional energy detection method when the noise was unknown which is the real scenario. Hence it is quite a robust method for spectrum sensing in Cognitive Radio when the noise is unknown.

As the sample number increases for performing spectrum sensing , the performance of the WPED method rises evidently. When the sample number is large enough the probability of detection is close to 1.

Cyclostationary spectrum sensing gives better results compared to Energy detection method at low Signal to Noise Ratios (SNRs). With Cyclostationary spectrum sensing, the primary user's modulation scheme can also be easily found out. However, Cyclostationary spectrum sensing is much more demanding computationally and is more complex than Energy detection spectrum sensing method.

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